MONTANA SUNPOWER

Volume 1:

ACTIVE SOLAR HOMES

MONTANA SUNPOWER

ACTIVE SOLAR HOMES

Prepared by

Eric Trimble

Energy Division
Montana Department of Natural Resources and Conservation
32 S. Ewing
Helena, MT 59620

Preface

Heat from the sun—solar energy or "sunpower"—has warmed the earth since its beginning and played a predominant role in the planet's evolution. It melted the ice-age glaciers to form oceans and lakes, changed the world's climates and seasons, and sparked the growth of myriad life forms.

It also has influenced human development. Through the ages, people have used the sun's energy directly and indirectly to grow their crops, power their ships, and, in general, structure their lives. Experience taught them that plants needed the sun's warmth and light to grow, and that shelters facing the sun stayed warmer during cold periods.

Although the first fact, basic to agriculture, has never escaped our attention, the latter principle probably deserves more notice than it has received. Historically, the traditional sources of heat—wood and coal—and the more recently developed sources that have largely taken their place—home heating oil, natural gas, and electricity—seemed to be obvious choices for meeting heating needs; these fuels were relatively cheap and there seemed to be no immediate shortage of supplies.

Now, however, dwindling supplies of nonrenewable fossil fuels and skyrocketing prices for those fuels have sparked an increased interest in finding alternative sources of energy. With this increased interest has come the growing realization that the same immense power that melted the glaciers might be used to heat our homes.

Montanans have long been known for their ingenuity and perseverance when faced with a challenge. Their response to the worldwide energy crisis of the last decade has been no exception. All across the state, enterprising Montanans from many different backgrounds have spent and are continuing to spend time, effort, and money to develop systems to capture the heat from the sun.

The *Montana Sunpower* series highlights the efforts of some of these Montanans to use the sun's energy to heat their homes. The first two volumes in this series, which describe active and passive solar homes, are surveys of existing residential solar systems. As such, they discuss the benefits and detriments, problems and solutions, and performance and livability of selected solar homes in the state. These volumes are not intended as solar design manuals, but rather as case studies of existing systems.

Future volumes in the *Montana Sunpower* series will discuss heat load calculations, solar retrofits to existing homes, and solar systems on large buildings. This series is augmented by other publications from the Department of Natural Resources and Conservation, such as the *Montana Solar Data Manual,* the *Montana Renewable Energy Handbook* and the *Montana Energy Saving Handbook for Homeowners.*

Table of Contents

Acknowledgments

The Montana Department of Natural Resources and Conservation (DNRC) acknowledges the following individuals for their assistance in producing this volume of the *Montana Sunpower* series: Eric Trimble for project descriptions, system schematics, photographs, on-site interviews with project developers, and project reviews; Louise Moore (DNRC) for technical review and production supervision; Mike Chapman (DNRC) for solar engineering review; June Virag (DNRC) for schematic preparation; D.C. Howard (DNRC) for layout and cover design; Marjorie Peterson (DNRC) for processing the text; Ellen Ditzler (DNRC) for proofreading; and Tom Livers and William Phippen (both DNRC) for editing and production coordination.

The department also wishes to thank the many homeowners, solar designers, and project developers whose assistance and cooperation made this effort possible.

Introduction

This first volume of the *Montana Sunpower* series examines 29 active solar homes across Montana, from Hamilton to Turner and from Arlee to Glendive. All projects highlighted in this volume were funded, in part, by The Department of Natural Resources and Conservation's Renewable Energy Program. Thus, these projects can be visited by the public if prior arrangements are made with the homeowners.

DNRC project reports and on-site interviews have provided information on how different active solar heating systems are working in Montana. Although thorough scientific data are available in some cases, the primary emphasis here is to present a subjective evaluation by the homeowners themselves concerning comfort, energy savings, costs, construction problems, and ways in which designs might be improved.

This book is not a design manual. Rather, it provides case studies of several homes heated by active solar systems. As such, it describes the trials, errors, and successes of several Montanans to design and use active solar heating systems in their homes. Although the discussions that follow won't answer all the questions Montanans may have about active system design and use, they should give residents an idea of the type of systems that have been found to be feasible in Montana.

The book is divided into two main sections: the first discusses active liquid systems, the second active air systems. Each section contains descriptions of several residential projects. The relative merits of each design type are discussed in the next section and in the conclusions.

Principles of Active Solar

As the name implies, active solar energy systems actively move heat from solar collectors to the area to be heated. These systems range from relatively simple flatplate air systems for direct space heating to more complicated, concentrating liquid systems for heating at higher temperatures.

Basic components of an active solar system include solar collectors, some type of heat transfer medium, such as liquid or air, pumps or fans to move the heat transfer medium, some control device for operating the pumps or fans and some heat-storage system.

The flatplate collector is the most common type of collector used in residential active systems. In a flatplate collector, incoming sunlight warms a blackened absorber surface. Most of the heat from the sunlight is trapped by a layer of glass or fiberglass on the top of the collector and by insulation behind the absorber plate. From here the heat is transferred to storage or heat outlets through an air or liquid medium circulated through the system.

In a concentrating collector, refractive lenses or reflective surfaces are used to focus sunlight on a heat-gathering point or a liquid-filled tube. Liquid in such a collector reaches relatively high temperatures before it is pumped to storage or heating points. For top efficiency, concentrating collectors are designed to follow the sun's path continuously.

Most active systems are regulated by thermostats, which activate the pumps or fans when collector temperatures are warm enough for heating. From the collector, the air or liquid is piped to storage—typically rock storage in air systems and tank storage in liquid systems. When storage temperatures are significantly higher than temperatures in the living area, heat is pumped into the living space.

Several types of liquid systems are now in use in Montana. Again, the most common type incorporates the basic flatplate collector, in which heat is transferred from the absorber plate to a series of liquid-filled tubes within the collector. Often the tubes themselves act as direct absorbers of sunlight, passing the heat to the liquid inside.

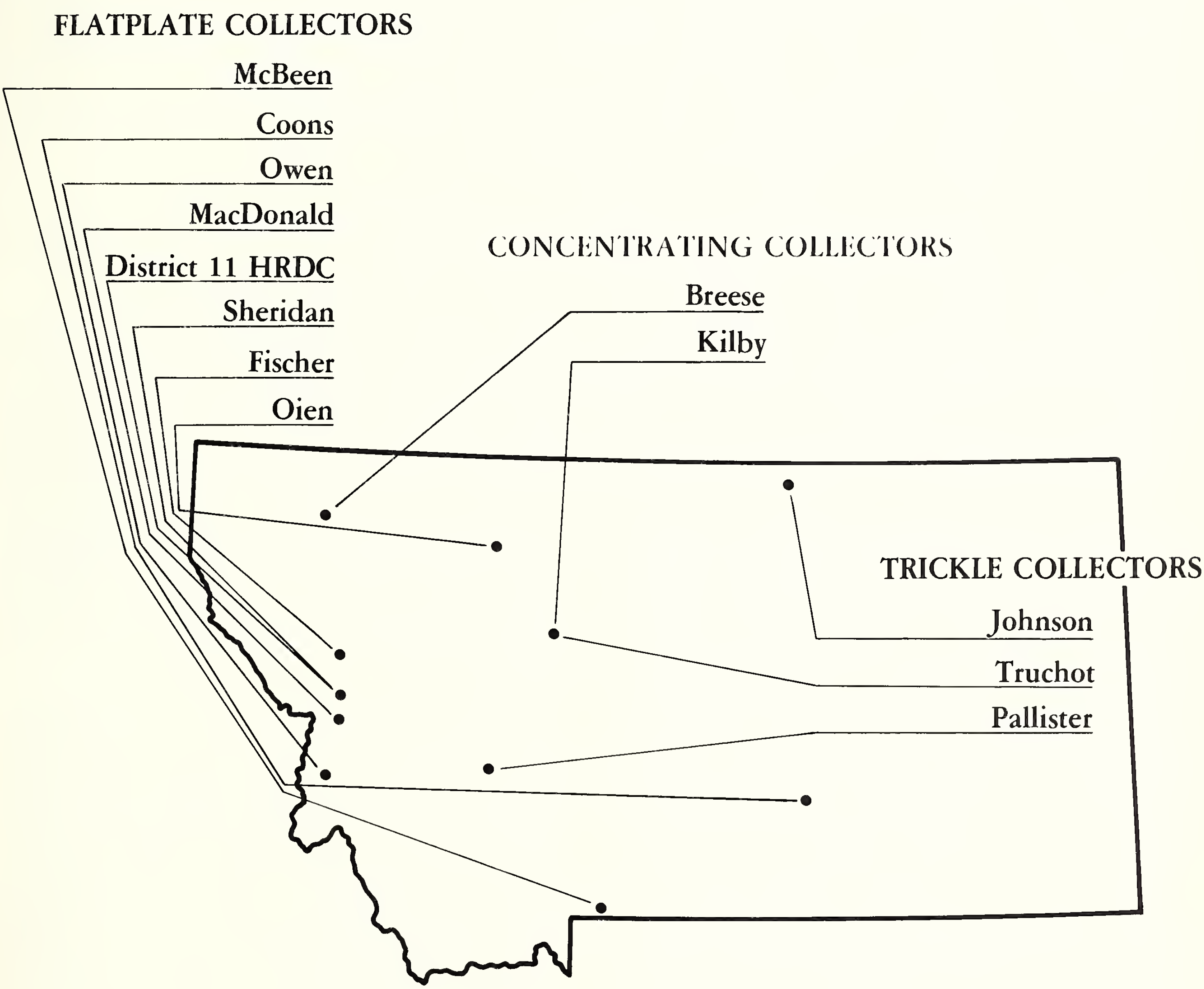
A variation of the flatplate collector is the trickle collector. The absorber plate in this design is corrugated; a heat-collecting liquid pumped to the top of the collector surface absorbs heat as it trickles down the troughs of the absorber plate. In some trickle systems, the liquid flows through a porous structure between two metal plates. Three trickle systems and two concentrating systems are examined in this volume.

Several climatic factors directly influence active solar systems. The most obvious, perhaps, is the amount of sunlight in a given locality, which affects sizing of the collectors and the amount of thermal storage needed. Of particular concern in Montana is the fact that extremely cold temperatures can freeze and damage pipes in liquid systems; two solutions to this problem are to use drain-down systems, which prevent water from being trapped in the collector during periods when sunlight is absent, or to use antifreeze in the transfer medium. Several ways to overcome such climatic constraints are discussed in this volume.

PART I

Active Liquid Systems

Projects Discussed in Part I



Arlee

John Fischer

John Fischer received a Renewable Energy Program grant of $20,000 to develop the Jocko Hollow Alternative Energy Effort in November 1976. The Jocko Hollow campground, located 1 mile north of Arlee on U.S. Highway 93, has since changed owners and is now operated by Louis and Mary Bevier. Funding was for a number of projects, both simple and complex, which demonstrate both active and passive solar systems. Since it was designed as a solar demonstration and teaching facility, visitors are encouraged at Jocko Hollow. Summer would be an ideal time to observe all the systems, though the public is welcome year round. The two active liquid systems demonstrated at the site are described here; an active air system is discussed in Part II of this book. The passive systems are described in Volume II of *Montana Sunpower.*

Cabin B — Hot Water System

Cabin B was one of three demonstration cabins constructed at Jocko Hollow. Space heating for the cabin is supplied by an active solar air system, described in the following chapter. An active liquid system in Cabin B preheats the domestic water supply before it enters a standard propane-burning hot water heater. Preheated liquid is stored in drums in an upstairs loft.

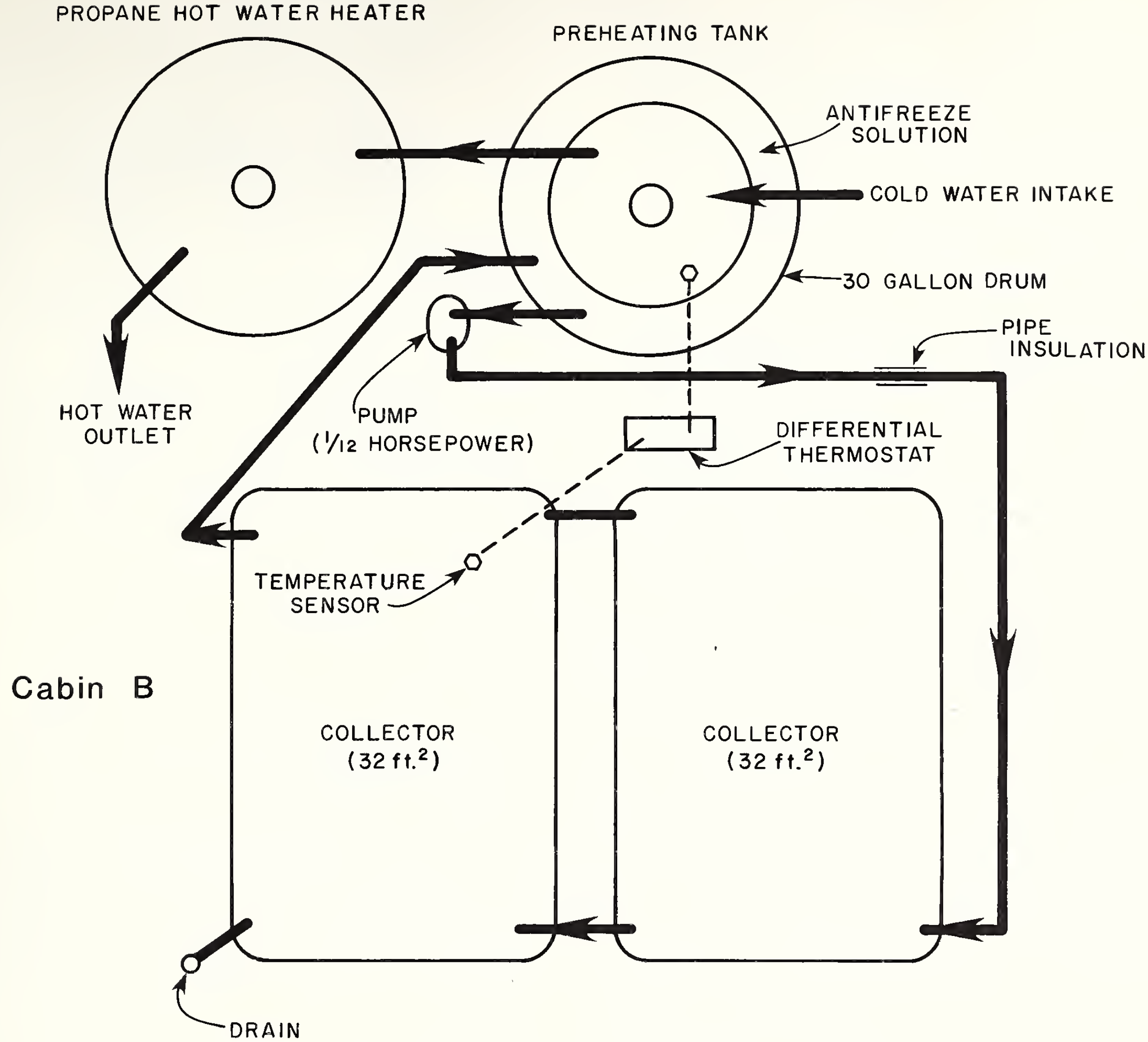
SYSTEM COMPONENTS AND OPERATION

Like many of the components used at Jocko Hollow, much of the Cabin B system was homemade. The collectors cover 64 square feet and were built in two 4-by-8-foot sections for ease in mounting. Half-inch plywood forms the backs of the collectors, which were insulated with foil-faced fiberglass. Second-hand aluminum roofing was used for the absorber plates. Copper tubing ½ inch in diameter was attached to the absorber plates, with 5 inches between each length of tube. The tubing was attached to and raised from the aluminum sheeting with Thermon® bonding cement, a high conductor of heat. High-temperature, flat black stove paint was sprayed on the absorber plates to increase their heat absorbing ability.

The collectors are glazed with Teflon FEP® film by Dupont on the inside and Sun-Lite® .025-inch premium by Kalwall on the outside. The two sheets are separated by ¾-inch cedar spacers and caulked with silicone. A metal flashing cap was mounted over the top of the collector and roof edge to protect the system from inclement weather. The lowest point of the system is equipped with a drain. Holes drilled in the bottom of the collectors help prevent condensation.

Heat from the collectors is transferred to and from storage tanks through a mixture of antifreeze and water. Fifteen gallons of antifreeze were mixed with 8 to 10 gallons of water to create a solution that will resist freezing to -40 °F. The solution is moved through the closed loop of tubing by a Bell and Gossett 1/12-horsepower circulation pump. The pumping cycle is controlled by a Rho Sigma® differential thermostat with one sensor located on the collector face and one sensor submerged in the antifreeze solution in the storage tank. When the collector is 20 °F warmer than the water in the storage tank, the pump is started. It continues to operate until the difference between the two temperatures is only 3 °F.

The system's storage tank consists of two 30-gallon drums, welded one on top of the other. Inside the tank is an old 30-gallon propane hot water tank. The vent stack area of the old tank creates a relatively large, exposed surface area. The solar-heated fluid fills the area between the drum wall and the inner tank, transferring heat to the tank. Cold water entering the propane tank at the bottom is heated by the warm walls of the tank. The heated water then flows out of the storage tank and into the conventional propane heater. Heat loss is reduced by insulating the pipes, storage tanks, and water heater.



Cabin B

PROBLEMS AND MODIFICATIONS

Original plans for the Cabin B hot water system called for constructing a thermosyphon or drain-down system to avoid the complexities of an antifreeze solution system. A thermosyphon system, however, demands that thermal storage be above the collectors, which was not possible in this particular building.

MATERIAL AND INSTALLATION COSTS

The following list summarizes the cost of the Cabin B water preheating system at 1977 prices:

Solar equipment	$132
Materials	199
Labor	175
TOTAL	$506

SYSTEM PERFORMANCE AND ECONOMICS

The economic outlook for the Cabin B hot water system is good. As of summer 1980, the system had reduced the use of propane by about one-half. With this performance level, a payback period of about eight years can be expected. The system contributes more hot water than is used in the small cabin and could be used in a much larger home with a greater need for hot water. Under those circumstances, the payback period would be shorter. The cost of electricity to run the circulation pump has been low.

Fischer advises that an additional savings might be obtained by substituting another, less expensive differential thermostat for the Rho Sigma model. His experience also indicates that some reconditioned pumps will perform as well as new ones, at a fraction of the cost.

Cabin A — Shower/Laundry Facility

This system heats water for the campground shower and laundry facility in the summer. Heat is stored in a water tank located inside Cabin A, where it provides space heating through a standard radiator system during the winter.

SYSTEM COMPONENTS AND OPERATION

The system incorporates 126 square feet of collector space, consisting of six 3-by-7-foot collectors manufactured by Libby Owens Ford. These collectors feature aluminum frames, 3½ inches of insulation, copper absorber plates, copper tubing, and double-glazing. Built on the drain-down principle, the system can be used year round without antifreeze. All pipes are pitched toward the storage tank so that when pump circulation stops, water drains into the tank.

The flow of water through the collector-to-storage cycle is regulated by a Rho Sigma 104® differential thermostat. This thermostat activates a Teel centrifugal pump when temperature sensors determine that the temperature of the collector is 20°F higher than the temperature of the storage water. When the temperature of the storage water is raised to within 3°F of the collector temperature, the pump is stopped. When the pump stops, a solenoid valve and an air valve at the highest point in the system open, allowing the pipes and collectors to drain completely into the storage tank. Because the system must be open to the air to drain, water in the storage tank is not used for domestic use. Instead, the home's cold water intake is run through 120 feet of copper coil submerged in the tank. In this way, stored solar heat is transferred to the water before it is piped into the hot water heaters.

The heated collector water is stored in a 340-gallon tank made by Snyder Industries. Composed of cross-linked, high-density polyolefin, the tank is insulated with 6 inches of fiberglass. If the sun has not heated the storage water to 80°F, it will be heated by a wood stove in Cabin A; the water is heated as it moves through a 50-foot copper coil in the top barrel of the homemade stove. With this auxiliary wood heating setup, the water system is used for space heating during the winter, even during cloudy periods.

PROBLEMS AND MODIFICATIONS

Since this system was retrofitted to the existing shower/laundry building and to Cabin A, alterations to both buildings were necessary. The roof of the shower house was removed and additional bracing was added to support a 50-degree roof, angled to the south. Angle iron 1½ inches thick was bolted to the modified roof to hold the six collectors. A 7-by-10-foot storage room with 6 inches of fiberglass insulation was added to the north side of Cabin A to house the storage equipment. Mounting the collectors on the showerhouse roof and adding the storage room to the back of Cabin A increased solar exposure and lessened the amount of heat lost while moving the collected heat to storage.

MATERIAL AND INSTALLATION COSTS

A summary of 1977 material and installation costs for the Cabin A hot water preheating system is as follows:

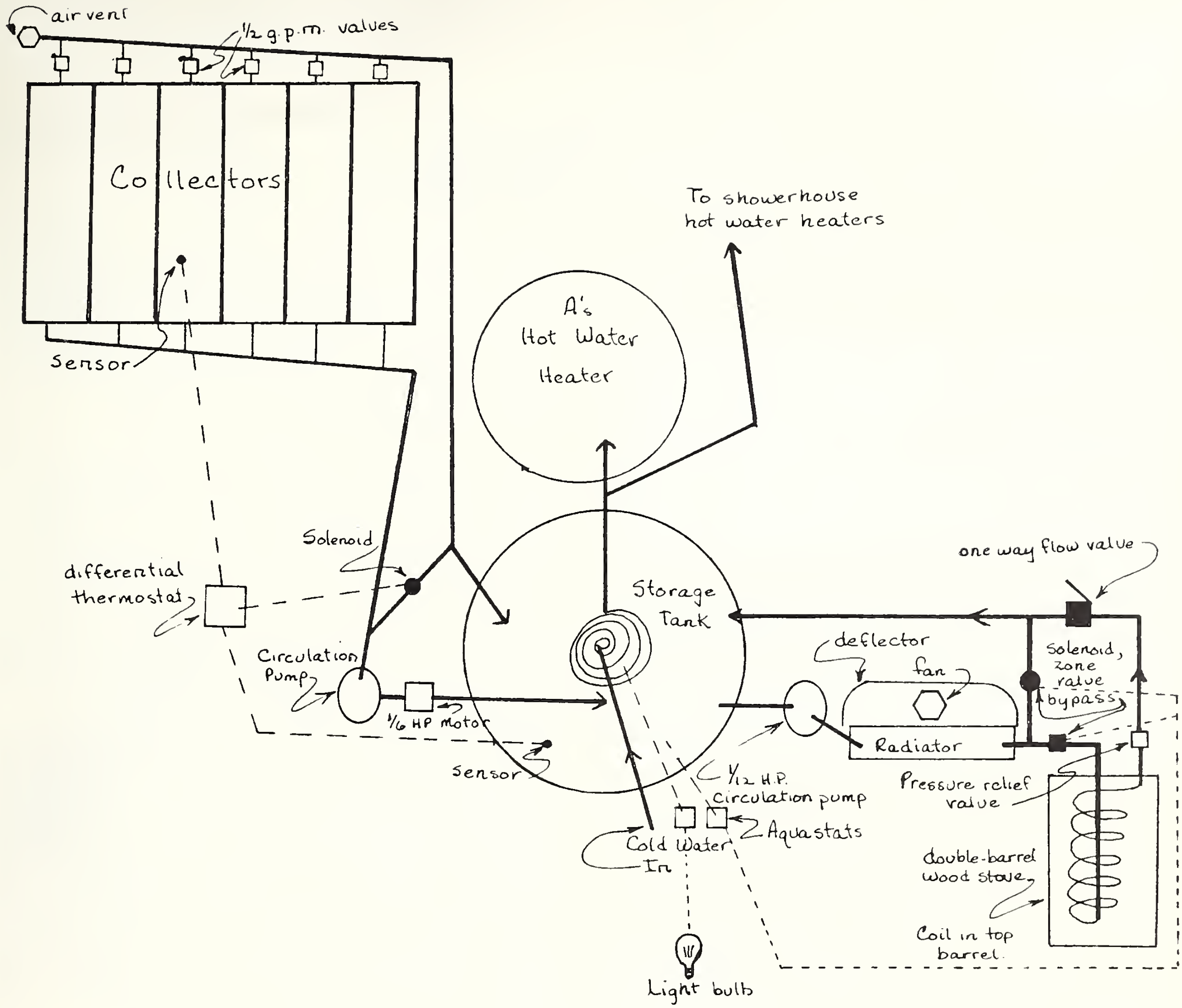
Solar equipment	$2,760
Materials	1,902
Labor	1,772
TOTAL	$6,434

SYSTEM PERFORMANCE AND ECONOMICS

Fuel cost savings through the summer of 1980 indicated the system was performing well. Estimated propane cost for operating the shower/laundry facility during the summer was $500. Since the system was installed,the propane cost has been reduced to $50 per year.

Economic performance of the Cabin A system is hard to determine due to sporadic occupancy and a lack of data for comparison. A savings of $75 per year is a modest estimate. If the wood heat backup system were included in the calculations, an additional savings of about $150 in space-heating costs might be anticipated. Payback for the entire system would then be about 10 years.

The Fischers believe that their homemade collectors on Cabin B performed almost as well as the commercially made Libby Owens Ford collectors on the shower/laundry building, although the commercial collectors are expected to last longer. This project, however, does point out the potential for significant cost savings by using homemade collectors; the entire Cabin B system cost about $500 to build, while the commercial collector panels alone cost about $1,500 uninstalled.


air vent
1/2 g.p.m. values
Collectors
Sensor
To showerhouse hot water heaters
A's Hot Water Heater
Solenoid
differential thermostat
Storage Tank
one way flow value
Circulation Pump
1/6 HP motor
deflector
fan
Solenoid, zone valve bypass
Radiator
Sensor
1/12 H.P. circulation pump
Pressure relief value
Aquastats
Cold Water In
double-barrel wood stove
Coil in top barrel
Light bulb

Cabin A

Missoula

Richard Sheridan

In 1976, Richard Sheridan of Missoula received an \$8,000 grant to design and build an active solar liquid system to provide space and water heating to his existing home. Because of topography and siting, Sheridan had to locate the collectors approximately 200 feet from the house. The project thus provided a unique look at remote collector retrofits.

Visitors are welcome, but are asked to make an appointment by writing or calling Sheridan at: Rt. 5, Pattee Canyon, Missoula, MT 59801; telephone: 543-7900.

SYSTEM COMPONENTS AND OPERATION

Sheridan's house was originally built with little regard for solar orientation and energy conservation. Located on the north-facing slope of a wooded canyon, the closest spot receiving adequate insolation was a meadow 200 feet from the house. In this meadow Sheridan built a 24-collector array, oriented due south at a 45-degree angle. These collectors are connected to the home's space-heating system, while a three-collector array nearer the house provides heat for domestic water.

Collectors for both systems are essentially the same. Absorber plates are 4-ounce copper sheets; a manifold of ½- and ¾-inch type "M" copper pipe was soldered to the plates. This assembly was then spray-painted with flat black Krylon® . Wood frames were built from 2-by-6-inch lumber and 3/8-inch exterior plywood. Fiberglass batt insulation was added between the absorber plate and the plywood backing. Finally, the collectors were glazed with a single layer of glass and mounted, and the individual collector manifolds were connected in series.

In both the hot water and space-heating systems, the heat-transfer medium was a solution of water and ethylene glycol with a -50 °F freezing point and a 240 °F boiling point. In the domestic hot water system, the fluid circulates through a 60-foot continuous coil of ¾-inch type "C" copper pipe inside the insulated heat storage tank. From here, the fluid enters a 5-gallon expansion tank before being pumped back to the collector. As a safeguard against contamination of domestic water by ethylene glycol, a second, separate 60-foot copper coil circulates the domestic water through the heat storage tank. From this preheating tank, water enters a conventional electric heater for final heating.

Two thermistors regulate the domestic hot water system. One is set to activate the system when the collector temperature is 15 °F higher than the temperature in storage; the pump will not shut off until collector temperatures fall 5 °F below storage temperatures. Such a setup prevents unnecessary cycling of the pump. Another thermistor sets a minimum collector temperature of 80 °F, to ensure that enough heat will be gained to justify operating the pump.

The space-heating system draws heat from 24 collectors set 70 to 200 feet from the house. These collectors are connected in series. The transfer fluid passes from the collector array to a series of copper fin-tube heat exchangers inside four heat-storage tanks—two 240-gallon tanks and two 500-gallon tanks. The four tanks provide a flexible storage capacity. As in the domestic hot water storage tanks, nondetergent motor oil covers the water to retain heat. From the storage tank, heated water passes through a water-to-air heat exchanger, or radiator, and into the forced-air duct system.

PROBLEMS AND MODIFICATIONS

Due to high temperatures in the solar collectors, thermal putty used to bridge the gap between the absorber plates and the manifold in the collectors liquified. Breaking this thermal connection significantly lowered collector performance. Thermon Manufacturing Company, which produced the Thermon type E-1® putty, replaced it with an improved compound, free of charge.

The system was initially designed with integrated water and space heating. Sheridan opted for two separate systems, however, to isolate the contribution of each.

MATERIAL AND INSTALLATION COSTS

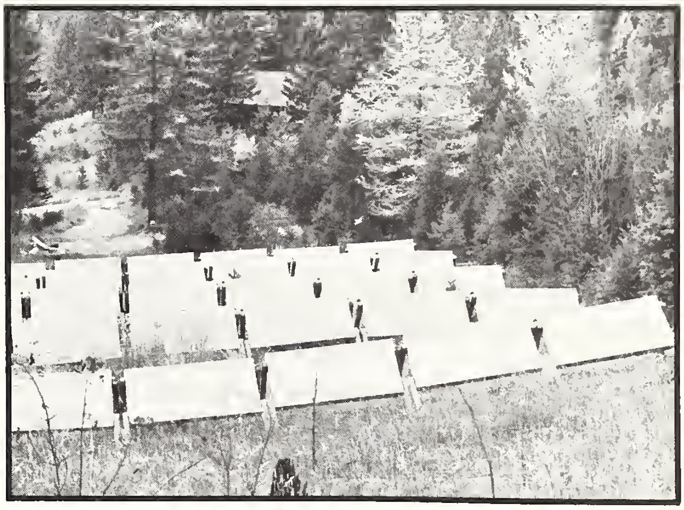
Initial installation costs totalled $8,200; $7,000 of this was spent on equipment and $1,200 in salary was paid to Sheridan's assistant. Sheridan himself donated a large amount of time to design, install, and repair the system.

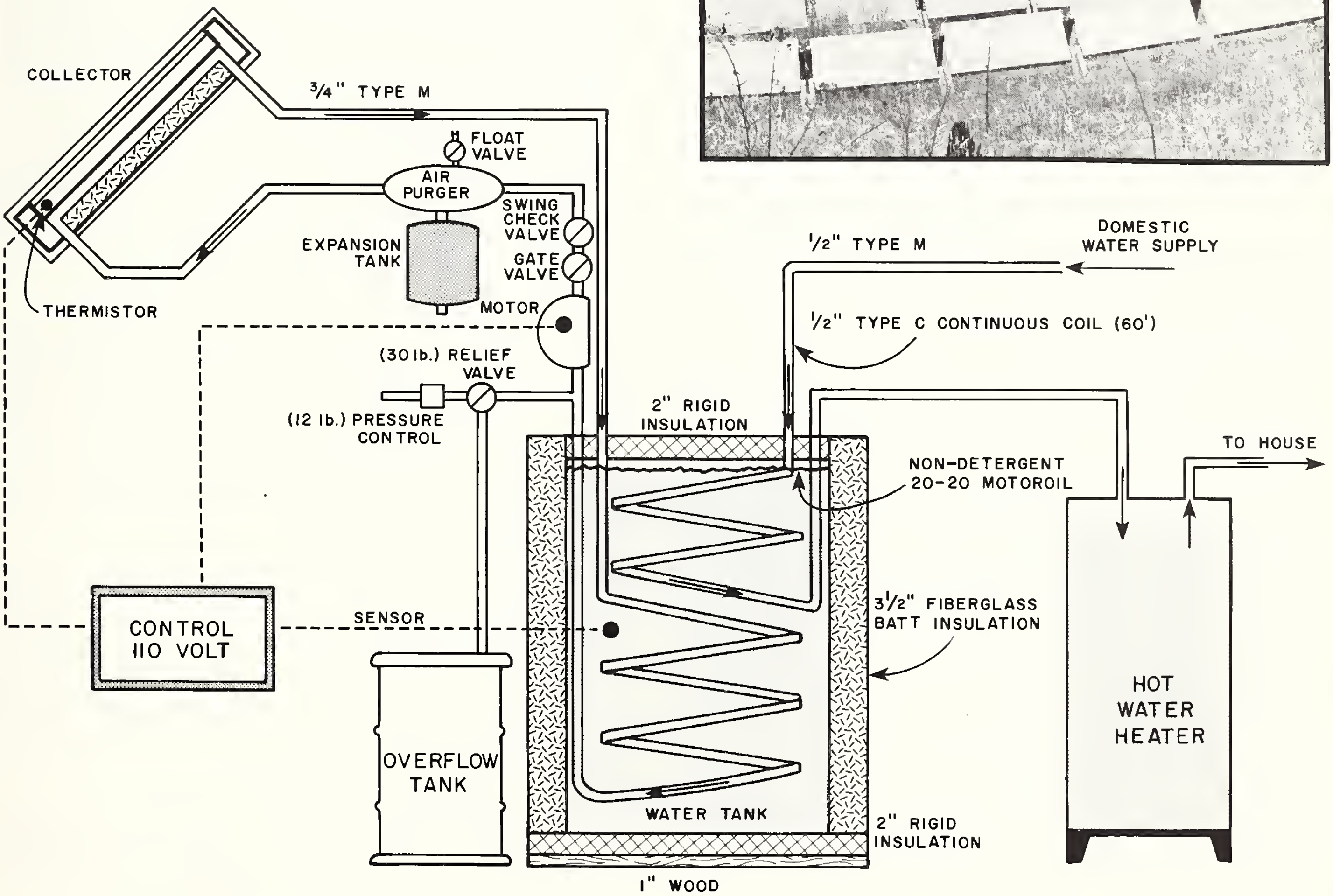
SYSTEM PERFORMANCE AND ECONOMICS

System performance was monitored from March through June 1979. While the solar system contributes only 7 percent of the space-heating requirements, approximately 65 percent of the domestic water heating requirements are met by solar preheating.

The low solar fraction contributed toward space heating can be attributed to several factors. Because the low winter sun is often shaded, the collector array puts out little heat from November to January. Also, due to the remote location of the collectors, 10 percent of the heat produced by the collectors is lost while it is being piped to the house. Design and control problems in the storage-to-house heat-exchange loop also contribute to heat loss.

Because of the low solar contribution, Sheridan's space heating system is not cost effective, although the domestic hot water system, in itself, would prove to be a good investment.





Missoula

District 11 HRDC

In July 1977, a grant of $15,000 was awarded through the Renewable Energy Program to the District 11 Human Resource Development Council (HRDC) in Missoula. The grant's purpose was to demonstrate the feasibility of adding solar domestic hot water systems to six different low-income homes. The goals of the project were threefold: to save energy and, thus, money for persons on low or fixed incomes, to demonstrate that amateur builders can install solar systems, and to encourage solar power as an alternative energy source in western Montana.

Because of these goals, some of the materials used and the sites chosen for the system were determined, in part, by practicability rather than optimal design. Because these systems exhibit many design and performance variations, this discussion will be confined to the common features of the systems.

These projects can be viewed by contacting the District 11 Human Resources Development Council at 728-3710, or by visiting council offices at 207 East Main, Missoula.

SYSTEM COMPONENTS AND OPERATION

The systems used by the District 11 HRDC are relatively simple. Collected solar heat is transferred to a nonfreezing liquid that is moved by an electric pump through pipes and into a storage tank. Inside the tank a heat exchanger transfers the heat directly to the domestic hot water supply. Additional heat is added to the water by a conventional electric heat exchanger. With the auxiliary heater, the supply of hot water can be kept constant.

The basic component of all the systems is a handbuilt flatplate collector. Three to four collectors, with a surface area of 18 square feet each, were mounted on each of the houses. The surface area needed was based on expected demand, with a ratio of 1 square foot of collector surface area for each gallon of water storage capacity.

Collector units were framed with redwood boards. The backs of the collectors were insulated with two 1-inch layers of foil-covered duct board. One inch of duct board was joined to the sides of each unit. Each heat absorber inside the collectors consists of five copper tubes soldered to .022-inch copper plate. The tubes, spaced 5 inches apart, carry the transfer fluid across the absorber plates from the bottom to the top of the collector.

Syltherm 44® , manufactured by Dow Corning, was selected as the liquid heat-transfer medium. Syltherm® is freeze-resistant to -50°F and remains liquid up to 450°F. Although Syltherm® expands manageably, transfer pipes and pumps are protected by an expansion tank joined with the closed-loop flow circuit. Thus, if the flow should stop during a period of intense sunlight, the system will not be damaged. Another benefit of Syltherm® is that it is among the least toxic chemicals that can be used to transfer heat. This protects occupants of the homes from being poisoned if the chemicals should somehow enter the domestic water supply.

An 80-gallon storage tank, made by Ford Products, was used in these systems. These tanks, made specifically for this use, contain a double-walled copper-tube heat exchanger with 15 square feet of surface area. The exchangers meet engineering standards for use with Syltherm 44® . A 4,500-watt electric element also is included in the tank to maintain desired water temperatures.

On projects with four collectors, a Grundfos Model EUP26-64F® pump was used to circulate the solar-heated fluid. A smaller Grunfos Model UPS20-42F® was used for the three-collector systems. These models were chosen because they have enough pumping power to overcome the severe flow restriction caused by friction within the collector tubing.

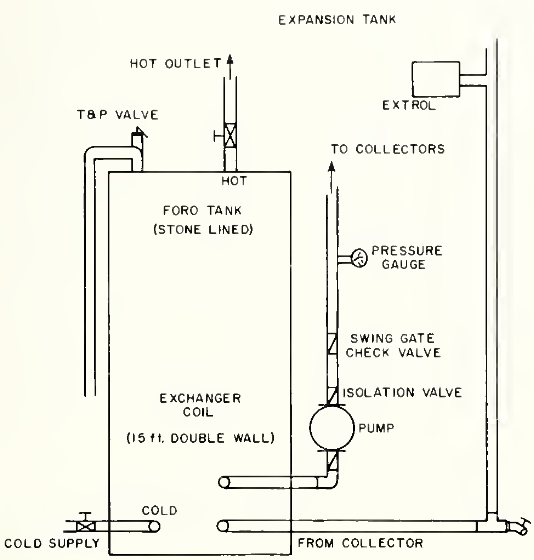
The solar pumping cycle is regulated with a Model 7412A® differential controller, made by Honeywell. Using a digital readout thermometer, the grantees

found that the best place to locate the control's sensor was between the tank's wall and its insulation. When the temperature at that location is lower than the temperature sensed on the collector, the pump starts. When the collector temperature drops below that of the tank, the pump stops.

PROBLEMS AND MODIFICATIONS

In 1979, when these projects were constructed, obtaining materials was a major problem. Delivery of the copper sheeting and storage tanks took longer than anticipated. Also, working with Syltherm®, like some other heating fluids, proved to be difficult; the fluid was hard to contain in the closed loop. Each collector unit required about one day for fabrication and testing; the rest of the system was installed in three to seven days by two people. The grantees strongly recommend air-drying the collectors several days before installation to allow enough time for black paint on the absorber surface to set.

Because heating fluids leak, the participants in the projects recommend pretesting of pipes and fittings to ensure proper operation and to prevent loss of the costly fluid. Collectors were tested with 50 pounds of air pressure for 45 minutes before being charged with fluid. All the differential controllers, pumps, and check valves were bench tested.



MATERIAL AND INSTALLATION COSTS

Following are the 1979 costs of materials for constructing one four-collector system:

Collectors	$ 484
Transfer fluid (40 lbs)	106
Tanks including freight	348
Pump	125
Differential controller (with sensors)	75
Plumbing and electrical supplies	261
Other	53
TOTAL	$1,452

The three-collector systems used slightly different components and cost about $1,188 each for materials. No labor costs are included for either system.

SYSTEM PERFORMANCE AND ECONOMICS

The District 11 HRDC has indicated that the systems operate with relatively few problems. However, the transfer fluid leaked in two systems. Also, the siting of one collector was less than desirable because it was partially shaded on winter evenings. In addition, one defective storage tank had to be replaced. All in all, during the first year of operation, owners experienced little trouble with their solar systems and the systems did not require much maintenance. Owners were asked only to monitor the pressure and hour gauges to ensure proper and safe operation.

Because performance varied from system to system, it is difficult to make an overall evaluation of the economic benefits of this project. From March to September the system supplied 100 percent of one home's hot water needs, although in January only 18 percent of home needs were supplied. For 1979, this amounted to an annual electricity savings of $167.91. At 1979 electricity rates, this savings leads to a payback period of about 8½ years, excluding labor costs. With a 10 percent annual electric rate increase, the payback period for the four-collector system would be 6½ years (5¼ years for the three-collector system), according to the HRDC estimate.

Hamilton

Gail Owen

Gail Owen was awarded a Renewable Energy Program grant of $12,262 in November 1976 to demonstrate both active solar air collection for space heating and solar domestic water heating for a new home of 1,377 square feet. The home, north of Hamilton and 2 miles west of U.S. Highway 93, may be seen by appointment only; call Owen at 363-2549.

Owen hoped to demonstrate that most of his home's heating needs could be supplied by alternative energy sources. This goal was to be obtained by integrating extraordinary insulation, a heat pump, and two solar flatplate collectors. Emphasis here is on the water-heating system, which incorporates a liquid solar collector.

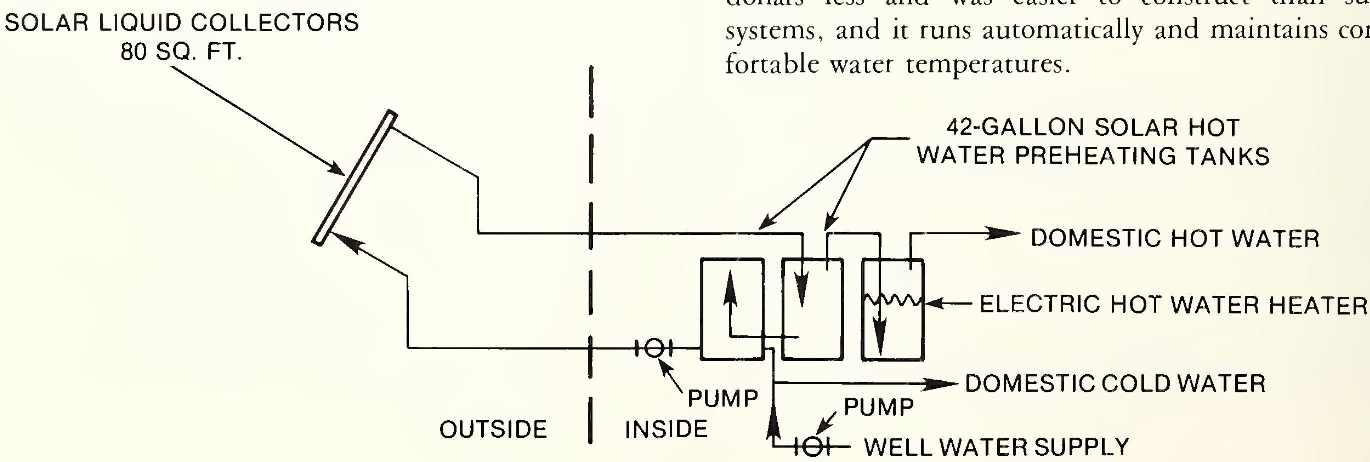
SYSTEM COMPONENTS AND OPERATION

Owen's hot water system is built into the south side of his home. The liquid collector features double-glazed glass windows mounted at a 60-degree angle to intercept solar radiation. Stainless steel absorber plates, covering 80 square feet and backed by rigid insulation, are used to capture the heat. Water to transfer collected heat is pumped from a well into two 42-gallon storage tanks and one 52-gallon tank, and from there to the collector. Heat is transferred from the absorber plates as the water is piped back and forth between the fins of the plates. Thermostatically controlled heating tape is attached to the bases of the plates to prevent freezing.

After entering at the bottom of the collector, water is pumped to the top of the collector and then back to the storage tanks into which the well water was originally pumped. These tanks are connected in series with a 52-gallon electric hot water heater for additional heating, if necessary.

The hot water system is controlled by two different devices. A thermostat at the absorber outlet operates in series with a photocell that senses ambient light levels. This ensures that the pump will run only when the sun is shining and when water leaving the solar collector is over 90° F. If the pump is operating on a sunny summer day and a thunderstorm rapidly hides the sun, the photocell will stop the pump. The photocell anticipates the coming drop in temperature before the resulting cooler water (less than 90°F) can enter the tanks. Similarly, in the early morning the photocell will start the pump when enough light is present. Thus, it anticipates the coming heat cycle more effectively than could a thermostat alone.

According to Owen, this control system—using a photocell with a thermostat—is less than ideal. In an ideal system, he claims, the circulating pumps would be controlled by temperatures at the absorber plate outlet and in the storage tanks. This would cause water to flow through the collectors only when it could be heated to a temperature higher than in the storage tanks. Nonetheless, Owen's system cost several hundred dollars less and was easier to construct than such systems, and it runs automatically and maintains comfortable water temperatures.



PROBLEMS AND MODIFICATIONS

The entire Owen project was constructed by members of his family, who contributed approximately 1,000 hours of labor. Gathering the necessary materials for the project proved difficult because the main components were shipped from outside Montana. Even relatively common materials such as insulation and wiring, he said, were not readily available in the Hamilton and Missoula areas. Consequently, about three months were spent driving, phoning, and writing to compile the materials. These problems occurred in 1976, however, and have been alleviated somewhat by the recent expansion of the alternative energy market.

The entire project, including the active air system, was completed in about three months, a much shorter period than anticipated. Long working days, plus the fact that most components were commercially fabricated, probably account for the relatively short construction period.

Owen's hot water system was originally designed to operate on the thermosyphon principle with one 52-gallon storage tank. In such a system, circulation occurs by convection, without the need for pumps. As water is heated in the collector panels, it becomes less dense and rises in much the same way warm air rises. Hypothetically, if a storage tank is placed above the collector, the colder water entering the collector should force the lighter, warmer water up into the tank, in turn circulating the denser cold water down to the collector.

Although Owen's thermosyphon system did function, he found that it did not work well enough to be used during western Montana winters. Thermosyphon circulation proved much too slow—three to four hours of sunlight were required to fully circulate the stored hot water, while the winter average is only six or seven hours of sunlight per day. Therefore, extensive modifications were necessary. These included installing electric pumps and adding two 42-gallon storage tanks, which brought the total storage capacity of the system to 136 gallons.

Freezing in the collectors also led to modifications. The original design called for a hot air duct that would extend from the central heat duct system to the collector and maintain frost-free performance. However, an early test with the duct in place showed that at -10 °F, the temperature at the bottom of the collector absorbers dipped to an unacceptable 17 °F. More outlets were added to the hot air duct, but this change provided inadequate. The problem was finally solved by attaching thermostatically controlled heat tapes along the base of the collector's absorbers. These tapes now ensure frost-free performance at the lowest temperatures commonly experienced. Owen admits that most of these problems stemmed from planning errors and oversights.

MATERIAL AND INSTALLATION COSTS

Purchase and installation costs of the complete hot water system at the Owen home totalled $5,520. Of this total, $3,070 was spent on materials. Labor costs, including the time spent modifying the system, increased from an original estimate of around $1,000 to $2,450 (computed at $7.50 per hour).

SYSTEM PERFORMANCE AND ECONOMICS

Owen's system performed far below the efficiency considered possible; annual efficiency was only 28.4 percent in 1977-78. In other words, of the solar energy theoretically available to the unit, only about 28 percent was converted to useful heat energy. In practical terms, however, the system converted solar power to heat at a rate seven times better than an electric water heater converts electric power to heat.

Owen attributes many of the performance failures of the system to siting deficiencies. Data on available sunshine proved to be inaccurate, he said; he estimated that in 1977-78 the site received about 33 percent less solar radiation, or insolation, than predicted from data based on a 1941 to 1970 period. The difference between actual and predicted insolation was especially large during the winter months, when heating needs are greatest.

Mineral buildup, or scaling, within the system also reduced its efficiency. In June 1980, Owen estimated that scaling had reduced the effectiveness of his system by about 50 percent. He planned to flush the system with a chemical solvent. Even though such a step may be costly, it should not be overlooked in Montana, where water often has a high mineral content.

Despite the problems and deficiencies of the system, solar energy has significantly lessened the home's fossil fuel use. Monitoring done by Owen between July 1977 and June 1978 revealed that nearly half of the home's hot water demand was being met by solar energy.

Owen estimates that he spent $75 per year to heat water from 1977 to 1979, thus saving $75 per year over conventional energy costs. However, the cost of energy to heat water by traditional means is currently low enough that even at a 50 percent reduction, the payback period on a relatively large initial investment is prohibitively long. Given his investment of $5,520, it would take at least 73 years to recover the system's costs at today's energy prices. Only a dramatic increase in energy prices in the near future would justify this particular solar investment.

Stevensville

John MacDonald

A Renewable Energy Program grant of $4,314 was given to John MacDonald in July 1977 to add a solar collection system to an existing hot water heating system. The project was to provide hot water and some of the space heating needs for his home. Arrangements to view the project can be made by contacting MacDonald at Rt. 3, 1516 Middle Burnt Fork Road, Stevensville, MT 59870; or by calling him at 777-3643.

SYSTEM COMPONENTS AND OPERATION

The structure and location of the MacDonald home made it necessary to place the solar collection panels about 100 feet downhill from the house. This downhill site made a drain-down system for freeze protection impractical. Thus, the panels were protected by using antifreeze in a closed loop.

Since the existing hot water or hydronic heating system had a stored capacity of 1,500 gallons, it was impractical to pump the solar-heated water directly into the system; too much heat would be lost in the process. Therefore, MacDonald chose to use a heat exchanger to transfer the solar heat from the antifreeze solution to the existing hydronic system.

Water in the home's existing system was heated by an electric boiler and a wood furnace. Both of these conventional heating units were connected to an extensive array of oversized fin-tube radiators and to a 1,500-gallon storage tank under the house. Water in the furnace heater also was heated by the pipes circulating water from storage to the wood furnace. Thus, heat exchanged from the panels to the large storage tank contributed to space heat as well as the hot water requirements of the house.

The solar collector for this system is mounted on a south-facing hillside at a 65-degree angle. The collector panels were made by MacDonald, who claims a home craftsman with average ability and a lot of time could build this type of collector with little assistance. The collector covers 360 square feet and consists of 10 separate boxes or panels. These panels are mounted onto a framework of rough-cut lumber anchored to reinforced concrete footings.

The collector was assembled in stages. First, the tubing grid for carrying the heat transfer fluid was soldered to backing sheets of 4-ounce copper. The tubes that carry the fluid from the bottom to the top of the collector, where it returns to the heat exchanger, are ¼ inch in diameter. The main supply pipes, which feed the fluid to the bottom of the collector and then carry the warmed fluid out of the collector, are ¾ inch in diameter. Using tubes smaller than the supply pipes to carry the fluid across the absorber plates slows the flow at the point where heat is conducted and convected to the fluid. At the same time, because the larger supply and return lines allow a faster flow, less heat is lost in the circulation process.

Next, boxes to hold each panel were constructed by gluing and nailing plywood strips together. These frames then were insulated with 3½ inches of foil-faced fiberglass insulation and 1 inch of dense rigid foam. The boxes were mounted in the framework and joined with bolts. The complete absorber plates then were placed inside the boxes and the upper and lower copper supply pipes for each panel were soldered together.

Finally, after pressure-testing the complete collector at 80 pounds per square inch, two layers of glass were laid into the grooved boxes; tempered patio-door glass was used. The upper sheet of glass on each panel was

supported by nails inserted into holes in the walls of the boxes, while the lower sheet was supported by wooden turnbuttons. All gaps were caulked with a silicone glazing compound.

The solar collection loop has a fluid capacity of 27 gallons. The mixture of antifreeze and water flows through expanded sections at the top of the collector into a ¾-inch plastic pipe that carries it to the heat exchanger in the house. The pipes are insulated with 3/8-inch tubular foam insulation and rest on a strip of polystyrene inside a 4-inch plastic drain pipe. The entire pipe array lies in a trench covered with 18 inches of dirt.

The supply line enters the upper part of the heat exchanger tank, which was built by fiberglassing the inside and outside of a rigid, 2-inch-thick polystyrene box, and covering it with a lid of 2-inch polystyrene. The solar-heated fluid enters the tank through small holes in the supply line. A Grundfos UPS 25® pump draws cooler water from the bottom of the tank back to the panels to complete the solar heating cycle.

That portion of the heat exchanger carrying water from the main heating system also was made by MacDonald. Using parts of salvaged steam radiator units, he assembled the exchanger in a serpentine shape. This design yielded a heat transfer area of about 130 square feet in a volume of 27 gallons, for a ratio of 4.8 square feet of surface area per gallon of transfer fluid. Water enters the bottom of the exchanger and is pumped by a Grundfos UPS 20® pump back to the central storage tank.

The pump on the collector loop is controlled by an aquastat at the collector. The aquastat contains a sensor bulb that is immersed in a metal cup of mineral oil. This cup is soldered to the supply line at the upper corner of the collector, near the point where the collector fluid is hottest. Another aquastat controls the pump on the heat exchanger loop; its sensor bulb is in the transfer fluid at the top of the exchanger tank. This arrangement automatically controls the solar-heating system. While less efficient than a differential controller, it is also less expensive and easier to install.

PROBLEMS AND MODIFICATIONS

This system required considerably more time to construct than had been anticipated. Slow delivery of essential materials and harsh winter conditions hampered work. Each collector panel required about 20 hours to construct; building the collector alone took about 200 hours, almost all of which was spent by MacDonald.

One design problem came from using plastic supply and return lines, which tended to shrink as fluid temperatures climbed. The supply line to the house shrank about 3 inches over its 75-foot length, which caused leakages at some fittings. As a result, MacDonald recommends that copper lines and fittings be used instead of plastic.

Several important modifications were made while constructing this system. Building a single large collector rather than several small ones resulted in a greater total collector surface area and fewer components. MacDonald modified and tested heat exchanger design at least three times before choosing the exchanger described. A great deal of time and many calculations were needed before the desired ratio of surface area to liquid volume was achieved.

Still, the heat exchanger has not performed efficiently. MacDonald believes that a critical amount of heat is lost in the exchange process. Future plans are to modify the system drastically by moving the collectors uphill, behind the house. If this were done, a drain-down system to protect the collectors from freezing then would be feasible and the closed loop with the heat exchanger would not be necessary. Water from the home's existing heating system could be pumped directly through the collectors, thereby transferring heat more efficiently.

MATERIAL AND INSTALLATION COSTS

Following is a summary of 1977-78 costs of materials and labor for installing the system. Labor exceeded 400 hours, including testing and modifications, and is conservatively estimated in this list.

Equipment	$ 411
Subcontract work	85
Unskilled labor	17
Communications	28
Supplies	3,302
Labor (MacDonald's)	471
TOTAL	$4,314

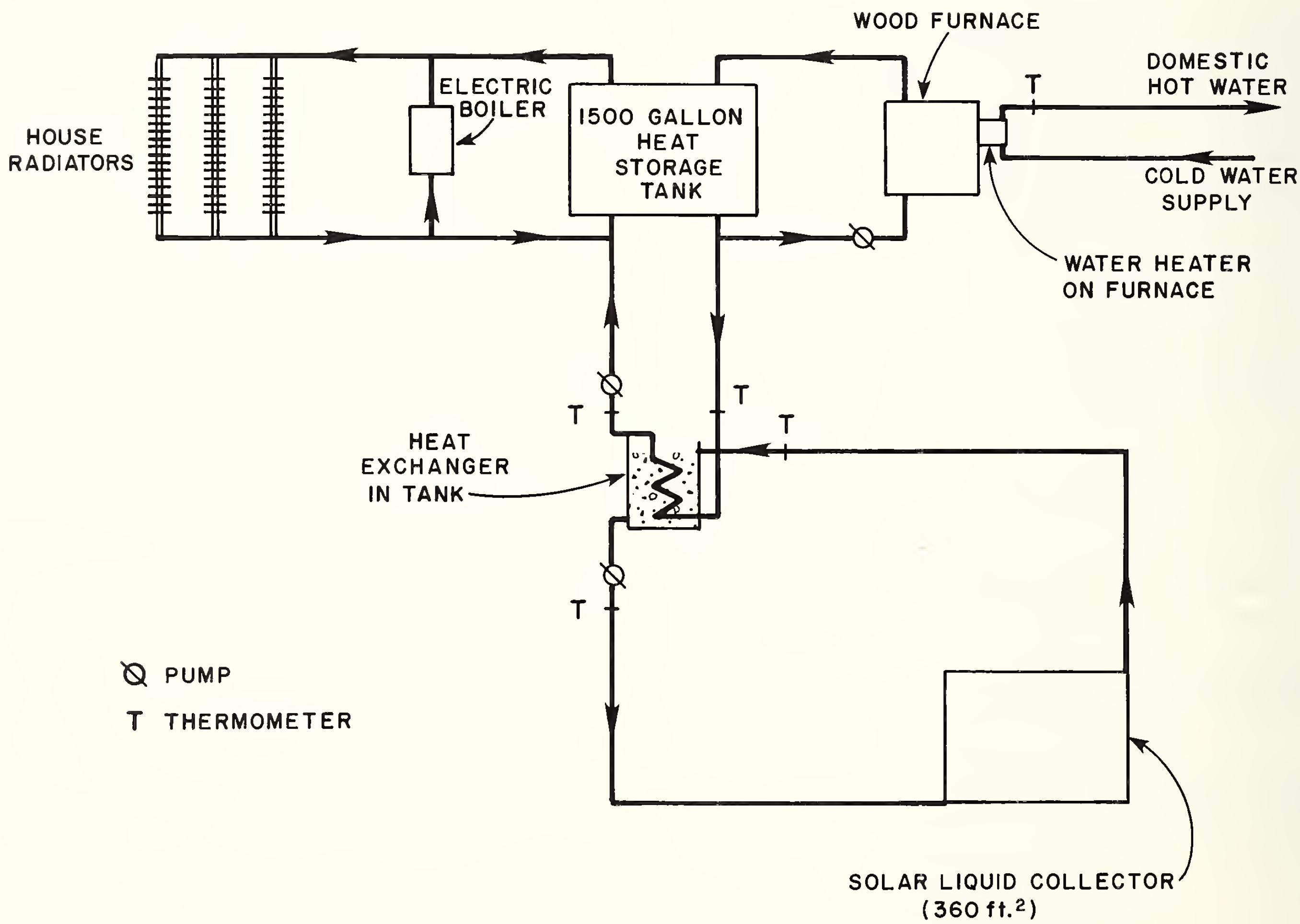
SYSTEM PERFORMANCE AND ECONOMICS

The collector system has been very effective in gathering and transferring solar heat. Performance monitoring revealed that on a sunny day the storage tank temperature rises by about 10 °F. This represents a contribution of about 120,000 Btu to the heating effort. Still, efficiency of heat transfer from the solar loop to the hydronic system appears to be only about 16 percent. Again, MacDonald attributes this low efficiency rate to heat loss at the exchanger.

Domestic water heating seems to have been significantly boosted by solar input. Domestic water heated by a coil through which the heated storage water flows, reaches temperatures from 90° to 100 °F. While this is not warm enough for practical use, it is much warmer than water in the well, which is only 50° to 55 °F.

The economic benefits of this system are limited. Due to high heat loss at the exchanger, space heating savings are minimal. Savings of electricity over the existing domestic hot water system amounted to $7.20 per month at the rate of 1.6¢ per kWh. If these savings were calculated at an annual rate of $43.20 (six months of effective use), the payback period for the system would be about 100 years.

MacDonald estimates, however, that if the proposed modifications were made, the system could contribute enough heat to save 1,000 kWh of electricity per month during the six-month heating season. Savings then would amount to $96 per year. Added to the savings gained through preheating domestic water, a total of $139 per year could be saved. The payback period then would be a more reasonable 31 years.



Orville Oien

Orville Oien received a grant from the Renewable Energy Program for $7,276 in July 1977. He proposed to retrofit his 40-year-old, 1,550-square-foot home north of Conrad with an active, liquid solar collection system. The project was designed to supplement space heating and to preheat domestic hot water. A special feature of this project is its use of reflectors to increase the efficiency of a minimal number of solar collectors. Arrangements to visit the project can be made by calling Oien at 276-3355, or by writing to him in care of the C.E. Ranch, Inc., R.R.3, Box 89, Conrad, MT 59425.

SYSTEM COMPONENTS AND OPERATIONS

Oien's project is designed to accommodate the climatic extremes of north-central Montana. Extremely cold temperatures and persistent, often high-velocity winds in the area can significantly reduce system efficiency by accelerating heat loss from the collector. The system is also designed to withstand damage from hail storms, which are common in the area.

These weather conditions were addressed by building a collector system along the peak of the home's south-facing roof and housing it in a specially constructed, open-shed structure. The shed is actually an extension of the north-facing roof, rising above the original roof peak. The collectors' efficiency in cold weather was increased by lining the ceiling and floor with reflective, delta-rib aluminum roofing. Hinged shutters were added to the shed so the collector area could be closed to prevent heat loss when solar radiation is inadequate for heating and to protect the collector glazing from hail. The backs of the shutters also were covered with aluminum roofing so that they would reflect radiation into the shed when the doors are open and lying on the roof. This design was expected not only to increase collector efficiency, but also to extend the length of the collection day.

At the heart of the collection system are copper absorber plates manufactured by the Olin Brass Company. The collectors are backed with plywood and insulation. Solar radiation is intercepted by salvaged patio-door glass, presealed as double glazing. Altogether, the collectors cover 98 square feet. Reflective roofing materials add another 450 square feet to the overall collector area.

A liquid heat-transfer medium flows through the system in a closed loop. The liquid, a freeze-resistant mixture containing equal parts of ethylene glycol and water, is moved through the piping by an electric pump at a rate of 2.45 gallons per hour per square foot of collector area. After absorbing heat in the collectors, the fluid flows down into a series of 14 glass-lined tanks in an insulated basement room. The fluid passes through a water-to-water heat exchanger in each of the tanks.

After passing through the last tank in the series, the fluid moves through copper tubing coiled around the outside of a 40-gallon tank. This tank contains domestic water preheated by the heat absorbed from the coiled tubing. Although this water preheating arrangement is not considered particularly efficient, it was chosen to avoid contaminating domestic water if the tubing developed a leak inside the tank. After water is preheated in the tank, it flows to a conventional electric water heater for further heating, if necessary.

This design offered two advantages. First, using several small tanks allowed Oien to build a storage system without altering his house to accommodate a single large tank; all the tanks fit through the existing doorways of the home. Second, using several tanks in series gave the system a more flexible storage capacity.

Total storage of about 1,700 gallons can be reduced to 720 gallons or 240 gallons simply by turning valves. Such a reduction of storage capacity permits greater control of storage temperature. If collector output temperature drops or if the hours of available sunlight decrease, a relatively high storage temperature can be maintained by heating less water.

A water-to-air heat exchanger, made by Oien, is used to convert the stored water heat to forced-air space heat. Tank water is pumped from storage to the exchanger, located in the cold air plenum of the existing oil-burning, forced-air system. A furnace fan circulates heated air to the room registers on demand.

A Deko-Labs Model TC-3® differential thermostat controls Oien's solar system. The thermostat activates the closed-loop pump when the collector temperature exceeds the stored-water temperature by a predetermined amount. The pump stops if the collectors cool or when the difference between storage temperature and collector temperature equals 16.5 °F.

PROBLEMS AND MODIFICATIONS

When this project was constructed in 1977, Oien found it difficult to acquire materials locally. Thus, most of the special solar equipment had to be ordered by mail. Some of the products didn't arrive until long after the expected shipment date. As a result, the construction schedule often was delayed.

Retrofitting the system to the home presented another problem. Constructing the shed to house the collectors was hampered by the distortion of the roof during its 40-year life. Because the roof was no longer uniformly plumb, square, or flat, it was impossible to prefabricate the shed to fit the roof. Thus, the shed had to be built on the roof.

Connecting the storage tanks in series posed another major problem. Because the transfer systems for moving heat from collector to storage and from storage to duct system were separate, several custom-made plumbing fittings were needed for each tank. In addition, each pipe connection had to be water-tight.

To date, only minor modifications have been made to Oien's system, although a major design change is planned for the future. The proposed change would move the storage system from its present location in an insulated room under the bedroom to a specially constructed room under the main living area of the home.

Several reasons justify this change, according to Oien. First, because the 14 tanks have about twice as much surface area as a single large tank of similar capacity, much of the stored heat escapes to the storage room. Because the lost heat does not contribute much to heating the main living spaces of the house, stored heat is used less effectively than possible. The design of the new storage room should allow the escaped heat to be vented directly from the storage room into the living space of the home. Acting as radiators, the tanks should heat more efficiently than they do through the original heat exchanger-to-duct method.

Second, this arrangement would use a lower grade of heat. While the exchanger method requires a storage temperature of at least 100 °F, the new design would require a stored temperature of only 70 °F to heat the main room to 65 °F. The heat thus saved would be nearly enough to heat the house for 12 hours on a very cold winter day.

Other benefits of such a modification are that heat would be immediately available, pumps and fans would be eliminated, storage would require no elaborate plumbing, and considerable labor expense and construction time would be saved.

MATERIAL AND INSTALLATION COSTS

The 1977 costs of Oien's system, without the proposed modification, are summarized as follows:

Labor costs, including salaries and benefits	$2,147
Building and material costs	4,588
Equipment costs	859
Supplies	160
Travel, administration, and other costs	104
TOTAL	$7,858

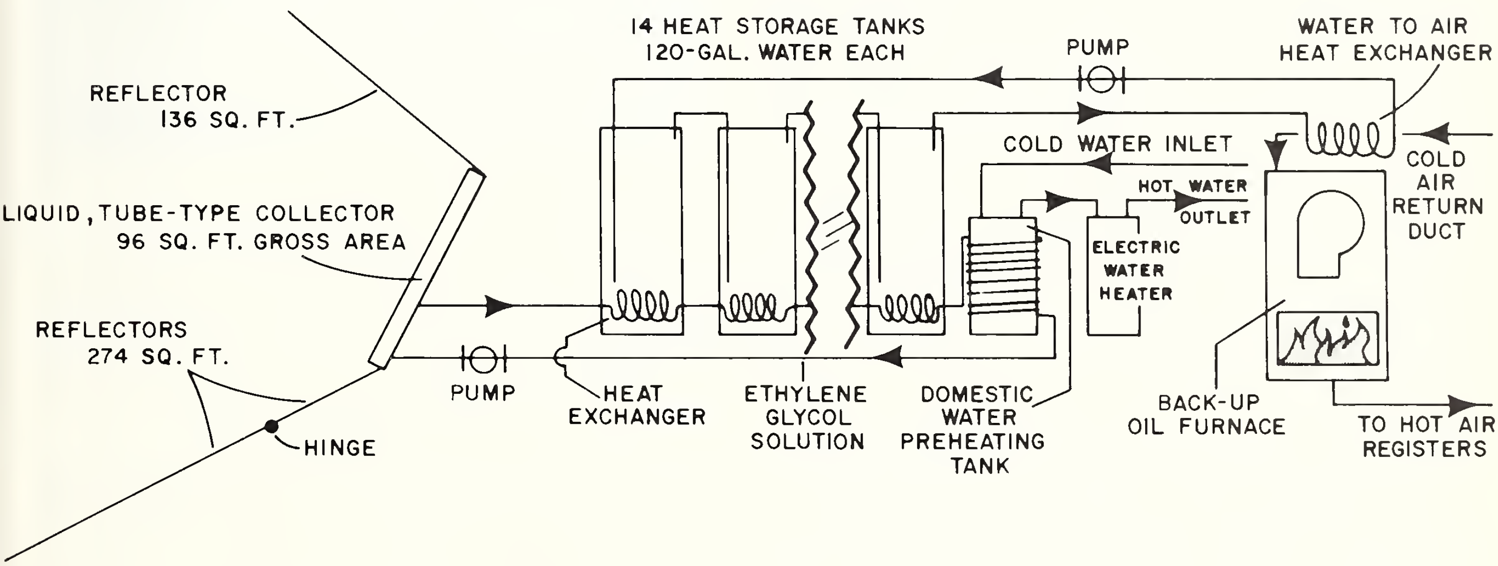
SYSTEM PERFORMANCE AND ECONOMICS

Performance data on Oien's system are based on the number of hours that the collector pump operated during a given period of time. Although the system was designed to operate normally at about 50 percent efficiency, Oien used a more conservative estimate of 30 percent efficiency to assess performance during its initial operation—from October 1977 to January 1978. To the extent that the number of collector pump operating hours represents the amount of sunlight available at the site, the initial findings are promising. Oien's findings for 1977-78 suggest an average of about six hours of sunlight per day. Indications are that the system will contribute notably to the home's winter space-heating needs.

Collector performance was significantly enhanced by the reflectors. Because of a delay in receiving the reflective material, the collectors operated without reflectors for five weeks. Even though winter was approaching and the days were shorter, collection days were longer after the reflectors were installed. Even on a clear December day, the reflector-assisted collectors gathered solar radiation for 6½ hours.

Oien's system was monitored by an independent engineer in 1980 through a grant administered by the Energy Division of DNRC; more detailed monitoring data are available to the public through the division.

The collector system cost $37.73 per square foot to build, including the reflective surfaces. Estimates from the first year of operation were that with fuel oil costs at $.46 per gallon, an annual savings of $215 per year would be realized. This calculation does not include possible savings on domestic hot water. With annual savings of $215 and a system cost of $7,858, the expected payback period would be 37 years.



Billings

James Coons

James Coons received a grant of $11,000 in November 1976 to demonstrate the feasibility of solar heating in the Billings climate. The project was to be monitored as a source of architectural and engineering data for current and future solar energy projects in the region. Coon's objective was to build an active liquid system to assist space and hot water preheating for a new, well-sited, well-insulated, two-story home with a basement. Coons predicted that about 30 percent of the heating needs of the 2,945-square-foot building could be met by the system on an average January day. The home is located at 10 Emerald Hills Drive in Billings, and may be seen by appointment.

SYSTEM COMPONENTS AND OPERATION

This project features a system of flatplate collectors through which a fluid is circulated and pumped to storage tanks. Heat stored in the tanks can be drawn through an exchanger into a duct system where a fan in the system's heat pump moves the warm air to the heating outlets. The heat pumps, made by Carrier, also serve as an auxiliary heat system. Domestic water heating also is supplemented by passing the water supply through a 25-gallon, steel preheating tank inside one of the storage tanks.

Collectors covering 600 square feet were mounted on the roof of the building. Manufactured by Solarmatic of Valrico, Fla., the collectors are double-glazed with glass of low iron content to reduce reflection. Heat is absorbed by an aluminum backing coated with black chrome.

Copper tubing with aluminum plating carries a liquid heat-transfer medium through the collectors. This liquid, which contains equal parts of ethylene glycol and distilled water, is circulated in a closed loop from the flatplate collectors through the storage tanks. A heat exchanger in the closed loop transfers collected heat from the fluid for water storage. This arrangement has two advantages: being almost frost free, it minimizes the amount of antifreeze solution required; also, it prevents loss of stored water if a problem develops in the collectors or in the heat gain loop. A small holding tank has been included so that the loop can be drained if necessary.

Collected heat is stored in two 1,050-gallon tanks made from galvanized corrugated culverts. The two tanks sit upright in the home's basement. One contains the 25-gallon water preheating tank. Both are insulated with commercially available fiberglass insulation.

From the storage tanks, warm water is pumped through a water-to-air heat exchanger by a 1/12-horsepower electric pump. Located at the plenum of the duct system, the pump fan forces air across the exchanger and through the duct system to the living areas. Dampers installed in the duct system allow airflow to be controlled.

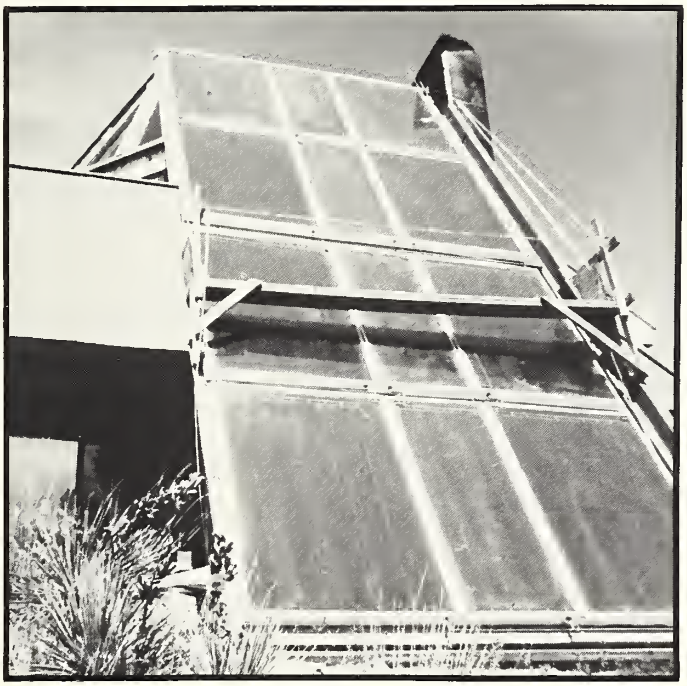
The heat pump controls the system's operation. If the temperature of the solar-heated water falls below 80°F, the circulating pump that moves the water through the heat exchanger automatically stops. The heat pump then carries the heating load.

An advantage of Coon's system is that during periods of warm weather the entire heat-transfer system can be placed in a cooling mode. Temperature-sensing devices can be readjusted to reverse the system. The heat-transfer fluid is circulated at night, cooling the stored water. Cooled water then can be pumped through the liquid-to-air heat exchanger, allowing cool air to be forced into the rooms. Unfortunately, the water preheating function of the system is lost in the cooling mode.

Materials for the project were acquired with relative ease. Most hardware items and solar fittings were available in Billings. The heat exchangers were modified from other heating or cooling systems; the water-to-water coils are the finned copper replacement coils for hot water boilers, and the water-to-air coil is a hot deck coil from a commercial home heating and cooling unit.

The most complex component to build was the control system. Because system operation was to be as automatic as possible, the control system incorporated synchronized relays, differential thermostats, and electric valves to regulate the alternating storage and heating phases.

Coons estimates that he spent about 300 hours building the system. Because he considered the system experimental, he expected to spend many more hours modifying and adjusting the solar array. Eight friends assisted in mounting the 200-to-300-pound collectors onto the home's 60-degree roof. Because the building site is sloped, the crew had to use a winch mounted on a vehicle parked behind the house to raise the collectors to the roof. Using scaffolds and safety ropes, it took the crew two days to mount the collectors. The collectors are supported on a frame of 2-by-2-inch boards.



PROBLEMS AND MODIFICATIONS

Coons tested the system before he put it into full use. The liquid heat-transfer piping system was tested with an air compressor; leaks were located and repaired. The electrical control system was tested by simulating operating conditions to verify the temperatures that activated pumps, valves, and fans. Minor modifications then were made. In addition, extra insulation was placed around the storage tanks, since too much heat was escaping.

Controls for the heat pump also have been modified. Originally, the home's room thermostat activated the heat pump when adjusted in the first stage. Now the room thermostat, in its first stage, activates the solar heat circulation pump and the heat exchange fan if the stored water is above 80 °F; a second stage activates the heat pump.

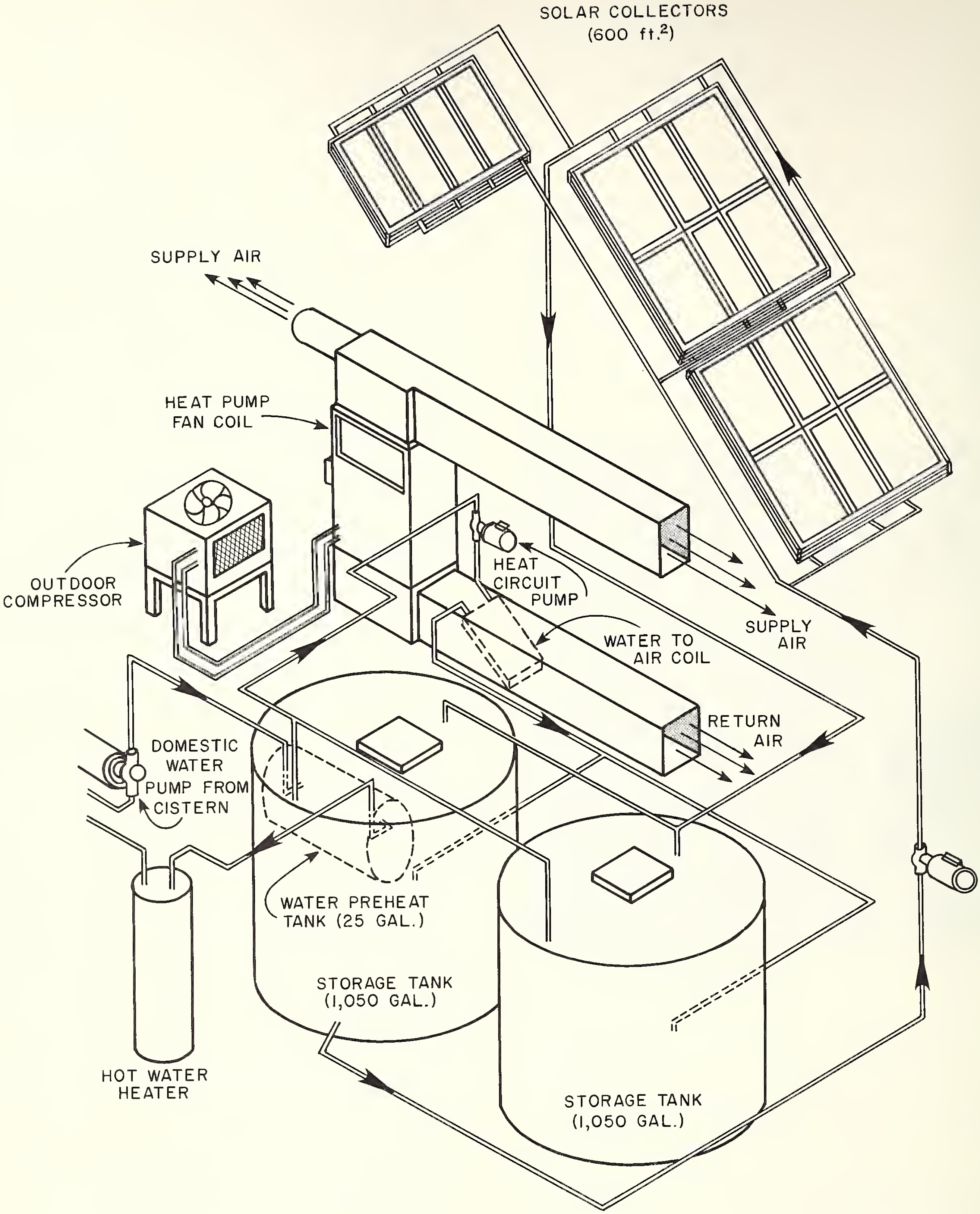
A serious problem occurred during early operations when, on two occasions under intense sunlight, the closed-loop circulation system failed. The closed system built up enough pressure to turn the heating solution to steam and blow open the relief valve. As a result, antifreeze was lost and air entered the pipes. After each malfunction, the system had to be recharged with the heat-transfer liquid.

Coons is considering two further modifications. Placing the heating coils on the return duct side of the heat pump would enable the solar heated water to be used jointly with the heat pump. Also, improving the integration of solar and heat pump systems would allow water at lower temperatures to be used for heating.

MATERIAL AND INSTALLATION COSTS

Coons bought many of the materials for this project at wholesale prices. Estimated labor costs are lower than commonly charged by professionals, but as Coons points out, skilled laborers would probably have done the work in less time. Material and labor costs, based on 1977 prices, were as follows:

Two Solarmatic® collectors	$ 7,227
Collector mounting	220
Storage tanks	1,418
Tank insulation	166
Control valves	263
Water-to-air heat exchanger	74
Water-to-water heat exchangers	271
Circulating pumps	193
Sensors, relays, and electrical devices	569
Hot water preheat tank	50
Piping, fittings	842
Pipe insulation	128
Expansion tank	83
Antifreeze solution and tank water	167
Labor	2,400
TOTAL	
Without labor	$11,671
With labor	14,071



SOLAR COLLECTORS
(600 ft.2)
SUPPLY AIR
HEAT PUMP
FAN COIL
OUTDOOR
COMPRESSOR
HEAT
CIRCUIT
PUMP
WATER TO
AIR COIL
SUPPLY
AIR
RETURN
AIR
DOMESTIC
WATER
PUMP FROM
CISTERN
WATER PREHEAT
TANK (25 GAL.)
STORAGE TANK
(1,050 GAL.)
HOT WATER
HEATER
STORAGE TANK
(1,050 GAL.)

SYSTEM PERFORMANCE AND ECONOMICS

In one 7½-hour period, just after the system began operating in January 1980, the temperature of the 1,050 gallons of storage water was raised from 64° to 104°F. Based on earlier calculations of the amount of solar energy available to the collectors on a clear day, such performance amounted to an efficiency rate of 20 percent, without considering external effects such as wind, atmospheric temperature variations, and haze. Even with conservative estimates of available sunlight in January, however, efficiency appears to have been closer to 64 percent. Coons suggests that the system's actual efficiency probably lies between 20 and 60 percent. Until available sunlight is accurately measured on the site, the system's true efficiency will not be known.

The payback period for Coons' system is also questionable due to the lack of precise on-site calculations for available solar energy. Nevertheless, payback calculations based on Coons' original estimate of solar energy availability and his initial findings on system efficiency yield the following results:

1. At an efficiency rate of 20 percent, the system would save $97.66 per year over conventional energy sources. (This figure is based on the local electrical rate of $.0246 per kWh.) At this efficiency, the payback period would be 117 years, considering the cost of the system, minus labor.

2. At an efficiency rate of 64 percent, the system would produce an annual savings of $312.53. The payback period then would be 36 years, based again on system costs, without labor.

Data on solar energy availability in the Billings area are compiled in *The Montana Solar Data Manual* written by Charless Fowlkes under a Renewable Energy grant. If these data are used, the results are:

1. At a 20 percent efficiency rate, the per-year savings would be $134.29, with a payback period of 85 years.

2. An efficiency rate of 64 percent would yield a savings of $429.74 per year, with a payback period of 26 years.

Marcus McBeen

In 1981, Marcus McBeen of Gardiner received a $4,837 Renewable Energy grant to design and build a cost-effective solar system for domestic hot water (DHW). McBeen sought to develop an efficient, low-cost system with the following characteristics:

— a collector cost of less than $7 per square foot
— a design life of 20 years
— good efficiency at temperature differentials up to 120 °F
— two-to-three days' thermal storage capacity
— an immunity from freezing
— an attractive design
— produced an 85 percent savings on energy costs;
— an 11-year payback.

McBeen completed his prototype system in May 1981. Visitors are welcome; for appointments contact McBeen at P.O. Box 64, Gardiner, MT 59030; telephone 848-7280.

SYSTEM COMPONENTS AND OPERATION

Most existing houses were not built with solar orientation in mind. Thus, retrofitting solar panels on the roof of such a dwelling is often difficult or impossible. For widespread application, McBeen designed and engineered a remote, modular domestic water heating system.

Terra Light® absorber plates were used in the collector. These plates consist of lightweight copper sheets, headers and tubes plated with black chrome. The collectors are housed in a sheet metal framework and covered with a 0.0001-inch Teflon® inner glazing and a low-iron glass outer glazing. Three 44-by-94-inch collectors are used, for a total surface area of 86 square feet.

A 300-gallon thermal storage tank is located underground directly beneath the collector. Both the tank and collector housings are integrated into one attractive structure. The tank was constructed from pressure treated plywood and a Gaco Western® rubber liner. The sides and top of the tank are lined with 18 inches of fiberglass insulation.

The relative locations of the collector and the tank allow for a drain-down system, which prevents damage from freezing. When temperatures at the top of the collector sufficiently exceed storage tank temperatures, a differential thermostat activates a pump that draws tank water to the top of the collector. The system is set to shut off when storage temperature reaches 180 °F.

Inside the storage tank, a heat-exchange coil transfers heat from the tank to pipes connected with the home's domestic hot water system. To lessen heat loss, the 20-foot pipes between the storage tank and the house are sandwiched between two pieces of 6-by-12-inch polystyrene and buried about 5 feet.

PROBLEMS AND MODIFICATIONS

The installed system was tested prior to operation and two leaks were discovered, one in the system's vacuum breaker and one in the fitting where a pipe penetrates the tank wall. Both were easily repaired.

No major modifications have been made, although the grantee is considering testing some new materials in a second-generation system. For example, fiberglass reinforced concrete is being considered for the collector housing to reduce labor costs. A high-temperature fiberglass storage tank and urethane tank insulation also are being considered as cost cutting measures.

MATERIAL AND INSTALLATION COSTS

Total costs for the project, at 1980 rates, are outlined below.

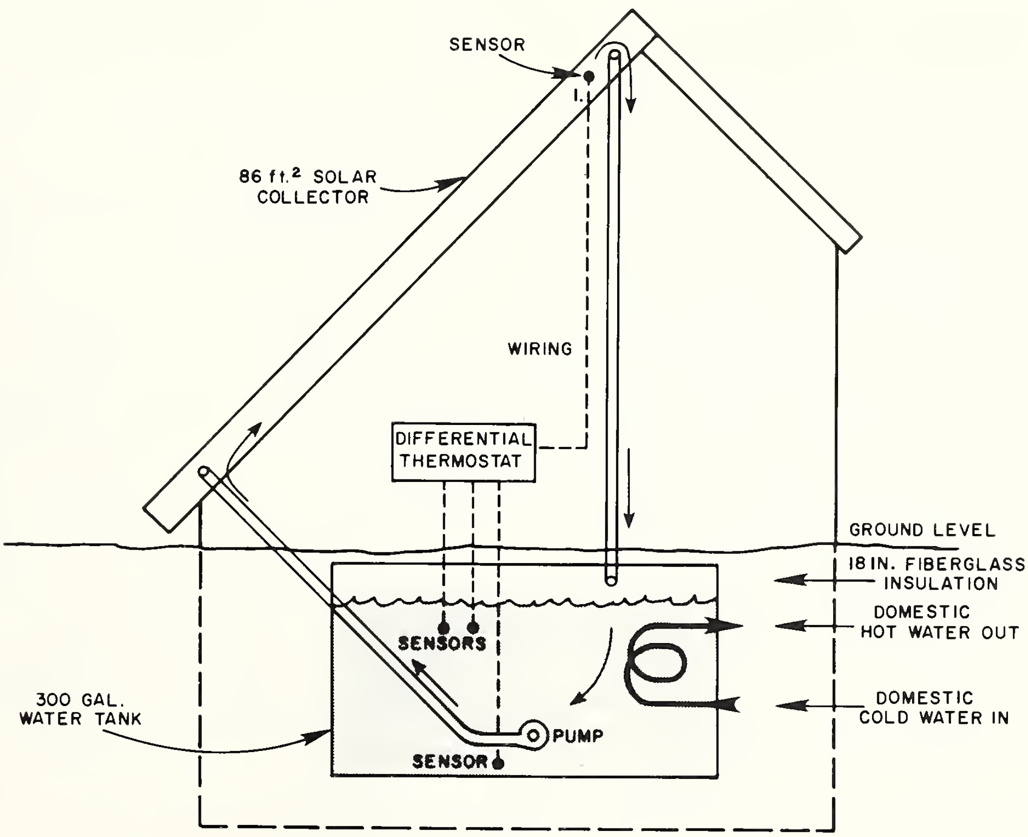
Contracted services	
Structure design	$1,500
Site preparation	338
Structure fabrication	815
Supplies	
Site preparation	472
Structure for system	3,537
Equipment purchase and rent	301
Materials shipment	269
Communications and administration	746
TOTAL	$7,978

McBeen spent $4,837 of renewable energy grant funds and $3,141 of his own money to build and install the system. He also spent approximately 100 hours of his own time to install the system. Of these costs, $5,732 were directly related to system installation, materials, and shipping. McBeen has proposed several cost-cutting measures. One of these, he says, would be to order materials for several systems in bulk.

SYSTEM PERFORMANCE AND ECONOMICS

This system has only been in operation since May 1981; thus extended performance data are not yet available. During the first spring, summer, and fall, the system provided 100 percent of the domestic hot water needs for the McBeen family of four. McBeen estimates an average solar domestic hot water fraction of 89 percent for his system.

Since this first unit was an engineering prototype, it is not particularly meaningful to calculate payback time. As a direct result of the experience and knowledge gained from this project, McBeen believes he can build an improved, second-generation system for $2,874. On a production scale, he believes it is possible to further reduce unit costs from $2,860 for several units to $2,470 for 100 units. On the basis of current electricity rates, a simple payback would run from 30 years for the prototype system to 13 years for the production system.



Great Falls

Lawrence Truchot

In 1977, Lawrence Truchot received a $7,500 Renewable Energy Program grant to help pay for an active solar trickle system on the roof of his new home south of Great Falls. Appointments to visit the project may be made by contacting Larry or Theresa Truchot, Rt. 2 South, Box 937, Great Falls, MT 59401; telephone 452-7443.

SYSTEM COMPONENTS AND OPERATION

As in most trickle collectors, the roof of Truchot's house constitutes the collector. The collector consists of 26-gauge galvanized metal roofing panels painted flat black with Imeron® high-temperature paint. The collector roof is glazed with tempered Thermopane® patio door replacements; total collector area is approximately 1,000 square feet.

Water is used as the heat-transfer medium. Truchot found it unnecessary to use antifreeze because of the drain-down nature of the trickle system. Water is stored in a 1,100-gallon fiberglass tank, commonly used for agricultural purposes. Automatic controls by Honeywell activate a ½-horsepower shallow-well pump to transfer water from the tank to the top of the collector when the roof temperature is significantly higher than the storage temperature. A cooling coil from an old refrigerator truck is used as a water-to-air heat exchanger, transferring heat from the storage water to the home's forced-air heating system.

PROBLEMS AND MODIFICATIONS

Truchot insulated his new house by pumping formaldehyde foam into the walls and ceilings. Formaldehyde foam now is not recommended in ceilings, and caused problems for Truchot. The odor from the formaldehyde persisted, possibly due to excess heat from the solar roof. After four years, Truchot installed a second ceiling behind the collector and vented the space between the two. This effort has apparently solved the odor problem.

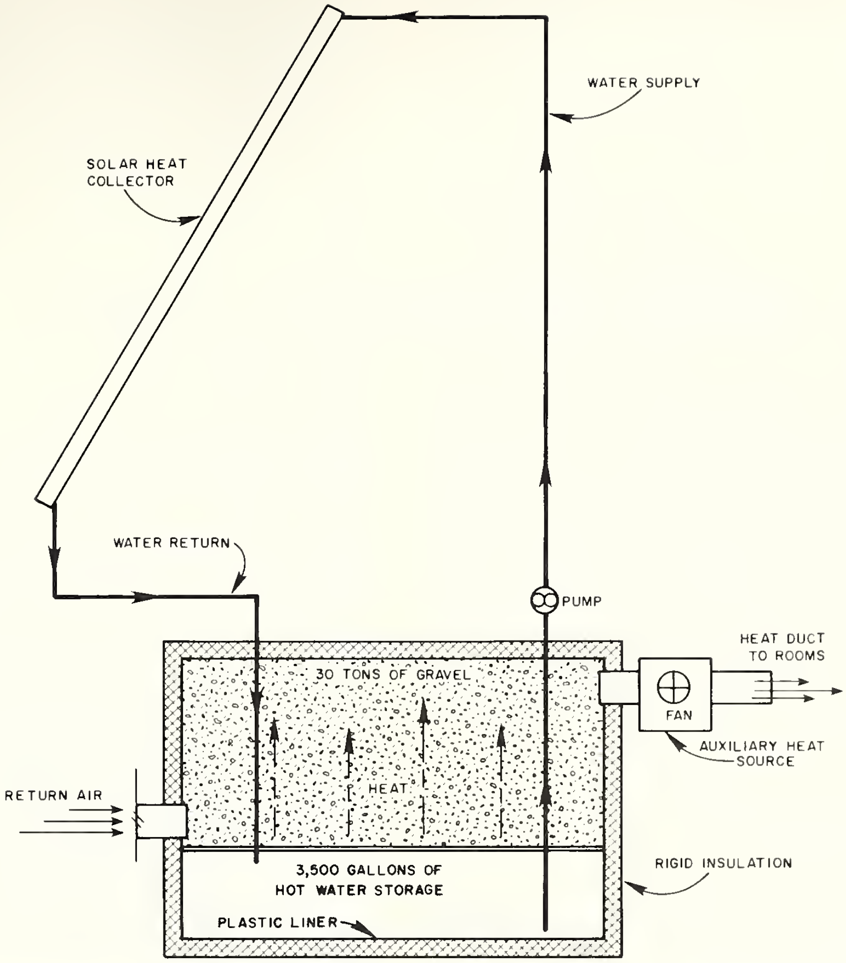
Truchot initially planned to store solar-gained heat in a concrete pit filled with water and rocks. In lieu of potential maintenance problems with a pit liner and the subsequent complications of pumping out the water and removing the rocks, however, he opted to spend a little more for a fiberglass tank. To his benefit, he found that the refrigeration coil worked very well as a water-to-air heat exchanger, a function the rocks were to have performed.

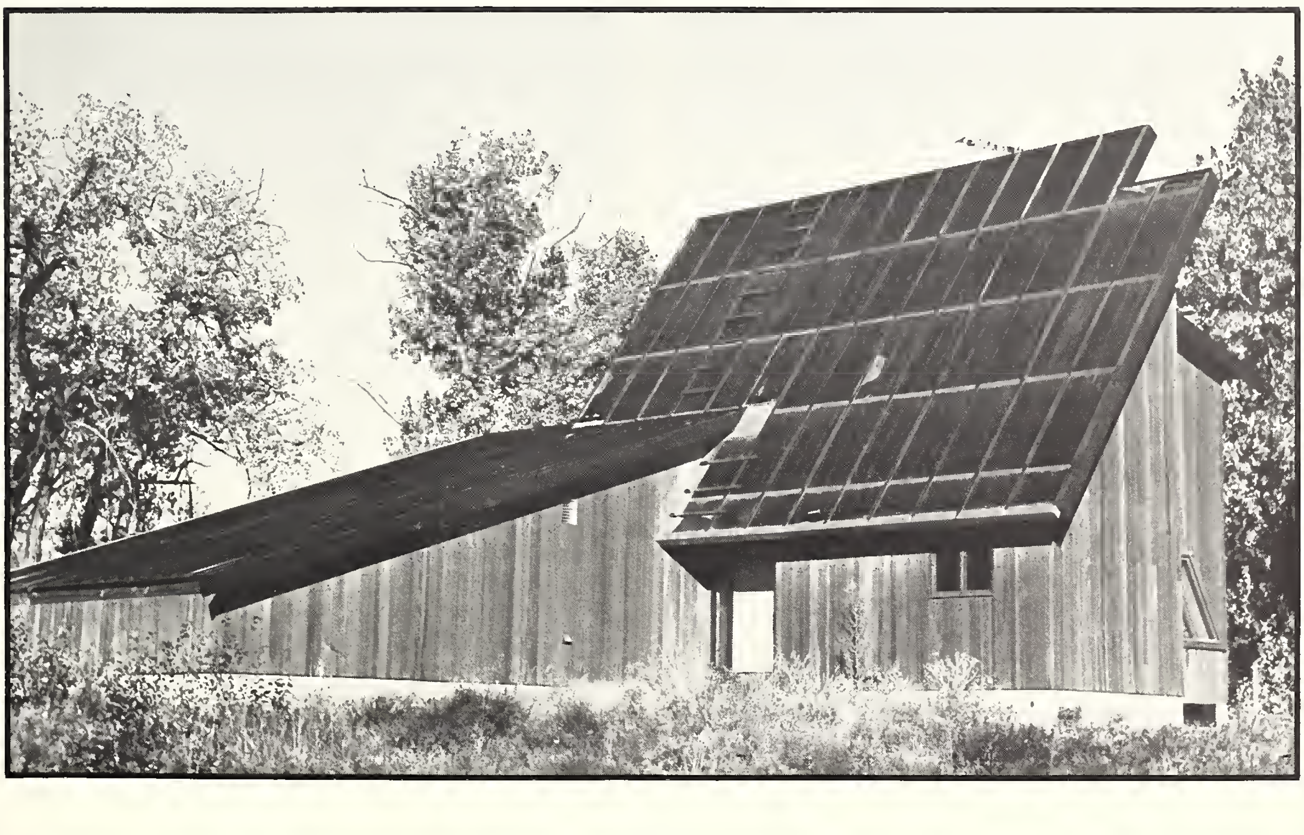
Excess heat also has been a problem. During construction, heat generated by the system destroyed the hot-water PVC supply line across the top of the roof, which Truchot replaced with copper pipe. Also, excess heat during the first summer of operation caused the collector's cover glass to expand, breaking a few panels. One problem not yet solved is the buildup of condensation on the back of the glass panels. A return gutter at the bottom of the collector does not catch this condensation, so significant amounts of water are lost during normal system operation.

SYSTEM PERFORMANCE AND ECONOMICS

The system has been in operation only since February 1981; thus long-term performance information is not yet available. Truchot has had no major problems with the system's operation, and his initial calculations place his solar contribution for January, February, and March 1981 at 50 percent. Truchot, who highly recommends water as a heat-collection medium, is especially pleased with the performance of his refrigeration coil heat exchanger and his inexpensive ½-horsepower shallow-well pump.

Truchot's installation and materials costs from 1979 to 1980 were $15,050, of which $7,500 were provided through a Renewable Energy grant. With an estimated savings of $535 the first year, the system would pay for itself in 28 years, without taking into account an increase in conventional fuel prices.


WATER SUPPLY
SOLAR HEAT
COLLECTOR
WATER RETURN
PUMP
HEAT DUCT
TO ROOMS
30 TONS OF GRAVEL
FAN
AUXILIARY HEAT
SOURCE
RETURN AIR
HEAT
3,500 GALLONS OF
HOT WATER STORAGE
RIGID INSULATION
PLASTIC LINER



Boulder

Philip and Blanche Pallister

The project was designed to show that an active solar trickle system and a wood-fired fireplace with water jackets could provide most of the space heating and domestic hot water for a large, well-insulated rural home. This project, part of which was financed through a DNRC Renewable Energy Program grant of $8,000, can be visited if prior arrangements are made. For appointments, please contact Philip or Blanche Pallister, Jaybird Ranch, Boulder, MT 59632; telephone 225-3648.

SYSTEM COMPONENTS AND OPERATION

The trickle panels, on the south, east, and west walls of the house, are corrugated and embossed aluminum, painted with Alu-prep® magnesium oxide primer and a black enamel high-temperature paint. The paint was allowed to cure for weeks before the panels were installed. The panels, framed in redwood, are double-glazed with low-lead patio-door-sized glass. Collection gutters at the bottom of the panels were fabricated in a sheet metal shop from 8-foot sections of aluminum. The total square footage of the solar panels represents about 27 percent of the house's floorspace; reflective sidewalks were designed to increase collector efficiency.

Bell and Gossett Series 60® ¼-horsepower pumps move an ethylene glycol and water transfer fluid between the collectors and a thermal storage tank in the basement. The tank was formed from a 2,500-gallon concrete septic tank, bivalved with no baffles. Forty-foot sections of 1-inch fin-tube pipe function as heat exchangers. Three exchangers for incoming heat, located at the bottom of the tank, connect with the three solar panel banks; one also connects with the two fireplace boilers. One outgoing heat exchanger in the top of the tank connects with the space-heating system and another connects with the domestic hot water system. The tank is well insulated—it is surrounded by 1 foot of fist-sized river rocks sandwiched between 1 foot of vermiculite below the rock and 1 foot of fiberglass above. The tank sits in an insulated concrete block room with 6 inches of foam in the walls.

Water jackets of ¼-inch mild steel surround the home's two fireplaces. Both fireplace boilers supply the same heat exchanger on a common line. Each boiler uses a Bell and Gossett 1/12-horsepower pump, a 30-pound relief valve, and a thermostatic control. One expansion tank is installed on line in the basement, along with an accessory 30-pound pressure relief valve and a pressure reduction valve.

A propane-fired hot water furnace provides backup heat for the solar and wood systems. This furnace is located on a direct line between the thermal storage tank and the space heat distribution system of copper pipes in the concrete slab floor. The domestic water supply enters a water softener, passes through a heat exchanger in the storage tank, returns to an insulated 150-gallon preheat storage tank, and then is pumped to a conventional water heater before distribution.

PROBLEMS AND MODIFICATIONS

The Pallisters found that several modifications were necessary to improve system performance. Because some of the paint in the solar collectors peeled due to intense

heat and the action of the ethylene glycol, the grantees recommend using prepainted corrugated aluminum in the collectors. Also, the material glazing the glass sheets together melted and the metal strip separating the glass sagged, which made replacing three of the panels and repairing two others necessary. Vents to keep excess heat from building up within the collectors proved inadequate; thus, the Pallisters installed aluminum strips over the edge of the panels to absorb and dissipate excess heat.

In addition, the original 1/12-horsepower pumps could not handle the load and had to be replaced with ¼-horsepower pumps. Condensation also proved to be a problem; it caused the ethylene-glycol solution to gel, which decreased the volume of the liquid transfer fluid. When not enough solution is in the system, the pumps suck air out of the troughs and lock up. This remains a major problem with the open trickle system.

Because of the problems mentioned, the grantees recommend against using a trickle system. The Pallisters are currently modifying their collector panels to use thin-walled copper pipes in a closed liquid system.

Other problems with the system occurred. The bivalved thermal storage tank leaked at a seam that was sealed with epoxy and automotive body putty. These sealants were replaced with a silicone caulk, which has worked well.

Also, each fireplace boiler initially had a monoflow valve to prevent overuse circulation. These valves did not function properly, however, and reverse circulation occurred. To remedy this, the Pallisters installed check valves in each boiler return line, as well as sensitive, 5-pound relief valves. An expansion tank and accessor relief valve were installed in the basement. These measures eliminated the need for monoflow valves.

Although the grantees used ¼-inch steel in the fireplace water jackets, they believe 7/32- or 3/16-inch steel would be adequate. All bolts in the jackets should be welded in place, according to the grantees.

MATERIAL AND INSTALLATION COSTS

The cost of this system, in 1980 dollars, is outlined below.

Wages and fringe benefits	$16,020
Fireplaces	2,680
Tank and tank room	4,781
Double wall-studding, sheeting, insulation	2,808
Auxiliary power and pump	107
Travel and delivery	789
Reflecting sidewalks	1,066
Domestic hot water preheat system	195
Panels	8,047
Control room	2,134
Furnace	1,402
Distribution and collection construction and Prestone, conventional	4,586
TOTAL	$44,615

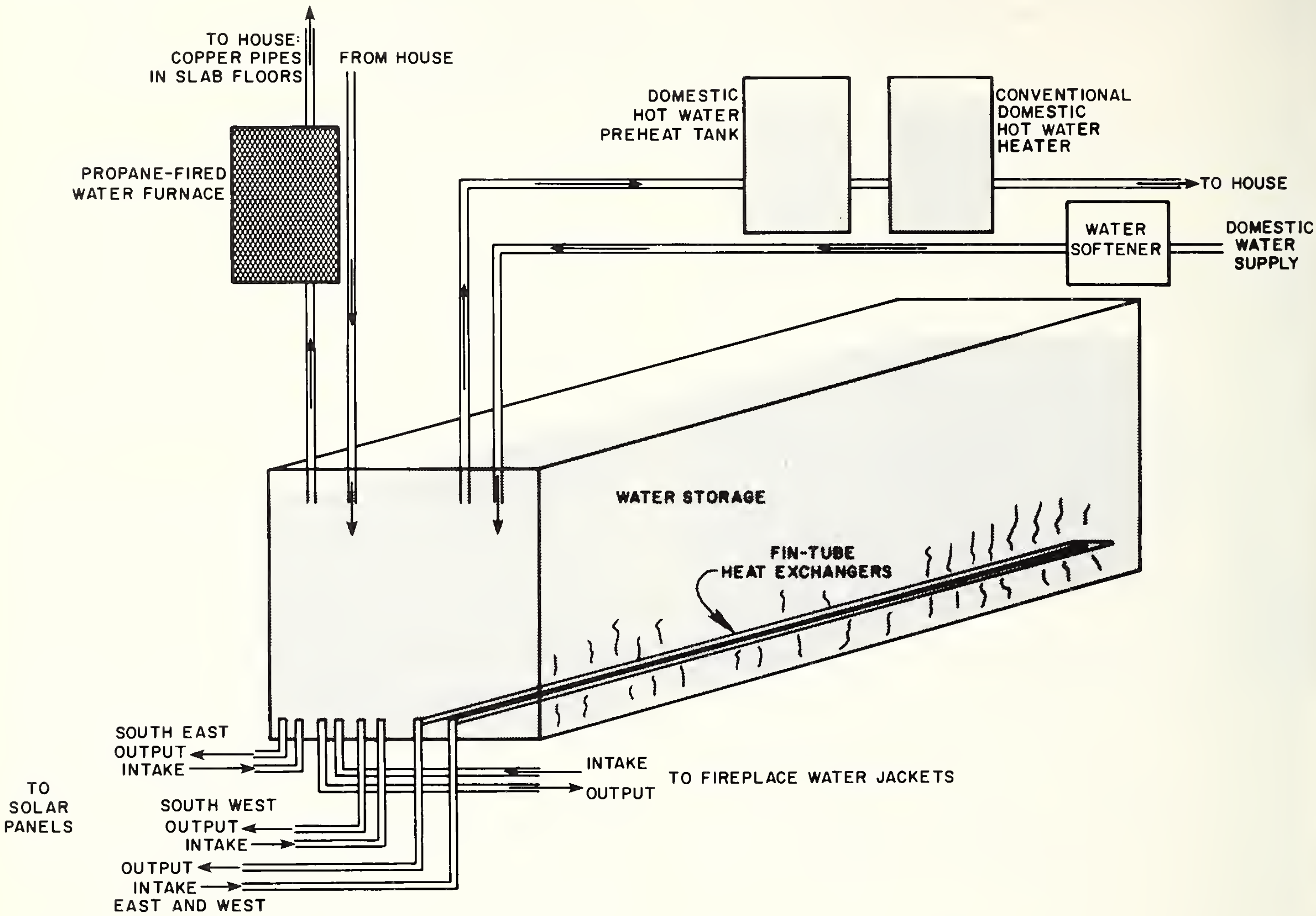
SYSTEM PERFORMANCE AND ECONOMICS

The Pallisters are exceptionally pleased with the performance of the wood-fired boilers, the thermal storage and the space heating and domestic hot water distribution systems. As mentioned, though, the trickle system has presented numerous problems. Nevertheless, any one of the three panel banks, when working, heats the storage tank to 120 °F in one day. The Pallisters estimate that when all three banks are working they provide at least 30 percent of the space heating and meet all the home's domestic hot water needs. Because the system was not completed until February 1981, it has not yet operated long enough to give reliable performance estimates.

Until more detailed performance information is available, a payback analysis is not possible. Nevertheless, a brief discussion of system costs and benefits seems merited. Some of the system costs represent costs

that would have been incurred during construction of the house alone; thus, the economic outlook for this system is brightened. Also, the Pallisters are currently modifying their trickle system into a closed liquid system; if the project were repeated, these modification costs would not occur again.

Although the solar portion of the system is currently performing below expectations, the wood-fired system is performing well and seems worth the cost. With an improved solar system, the integration of solar and wood heating should prove cost-beneficial, as thermal storage and heat distribution from a number of heat sources would be integrated into one system.



Turner

Otis Johnson

Otis Johnson of Turner was awarded a grant of $7,000 in July 1977 to retrofit his 1,344-square-foot home with a solar system for space and domestic water heating. The home, which included a basement, was well insulated when built. Johnson intended to show that a solar project of this scale could be constructed without using uncommon, hard-to-find materials. Visitors may view the home by making arrangements with Johnson at Box 157, Turner, MT 59542; telephone 379-2323.

SYSTEM COMPONENTS AND OPERATION

Even though the Johnson house existed before this proposal was undertaken, the project was not entirely a retrofit; the house had been constructed so that solar heating could be added later. The south-facing roof of the home was properly angled for solar collection. Johnson made the entire south roof into a collector, which gave him 1,500 square feet of surface area for absorbing the sun's energy. Collected heat is stored in a large tank under the garage, which was added to the house as part of the solar-heating system.

Water is pumped from the storage tank to the top of the roof collector. It then absorbs heat as it trickles down the corrugated roofing of the collector. From the bottom of the collector, the water flows back to the storage tank. Because this heat-transfer liquid flows from the heat-storing tank to the collector and then back to storage, the water remains warm enough to prevent freezing. A heat exchanger between the tank and the ductwork of the existing natural gas furnace also makes the stored solar heat usable for space heating. Cold water that flows through a small tank inside the large tank is preheated before it enters the domestic hot water heater.

The major component of this system is the large, homemade, flatplate collector. To make the roof into a collector, the existing corrugated aluminum roofing was painted with a commercial flat metal etching paint. Redwood strips were used to support and hold a fiberglass cover. Sunlight Premium II® fiberglass panels made by the Kalwall Corporation, used for the solar intercepting surface, were attached with aluminum screw fasteners and neoprene washers. All seams were sealed with silicone rubber caulking.

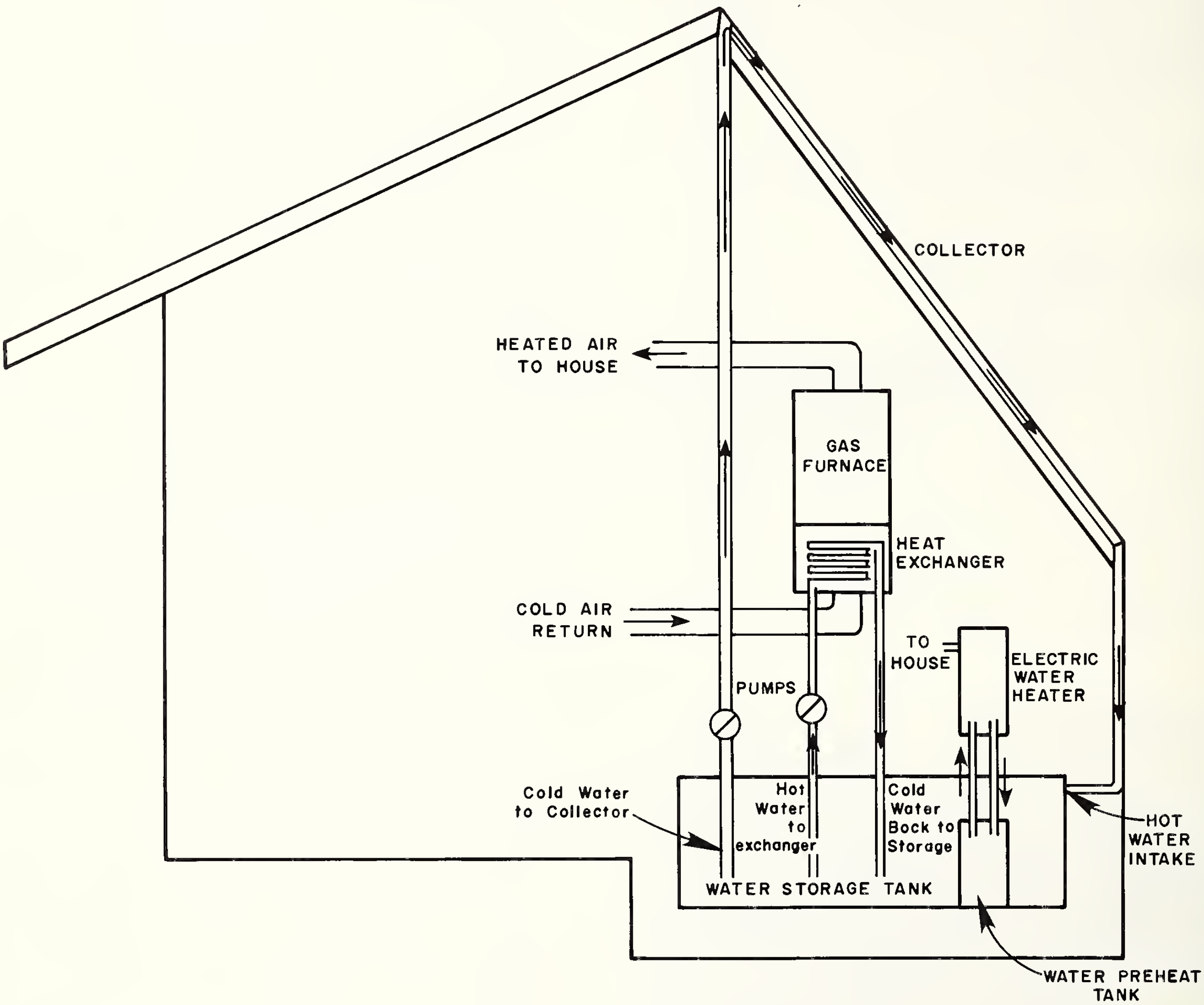
Water provides the heat-transfer medium for this system. Although freeze protection was not necessary, the water was chemically treated to limit corrosion of the aluminum roofing. Such treatment is necessary because the water flows directly on the roofing and is not enclosed in pipes and tubes, as in most liquid collector systems. A differential thermocouple automatically regulates flow through the collector. This device, a Heliotrope General Delta-T® , senses the temperatures of the roof and the stored water and activates a pump to circulate water over the collector when its surface is warm enough to heat the water.

The controls, pump, and heat-storage system are in the garage, which was built so that its roof would align with that of the house and form a part of the collector. The heat-storage tank, 6 feet beneath the floor of the

garage, was constructed of reinforced concrete, waterproofed on the inside with a special epoxy paint and insulated on the outside with 4 inches of polystyrene. A cover of wood and polystyrene, sealed with silicone rubber and epoxy paint, was built for the 3,600-gallon tank.

Domestic water is preheated when cold water flows through a 52-gallon tank submerged in the main storage tank. The water is piped from this submerged tank into an electric water heater adjusted to heat the water to 135 °F.

Two electric pumps are used to circulate the water. A Grundfos® circulator pump moves water from storage up to the top of the collector. When space heat is required, a Teel® circulator pump moves heated water to the heat exchanger, located in a cabinet under the gas furnace in the cold air return duct. In this cabinet two heat exchanger coils, built by Carrier, were connected in series. Locating the exchanger in the cold air return allows incoming air to be warmed before it goes into the furnace. Placing the exchanger on the warm air outlet would have made the furnace heat the water in the coil, thus reducing the contribution of the solar heat. Warm air is distributed through the house by the existing furnace fan. A conventional thermostat regulates operation of the backup furnace.



PROBLEMS AND MODIFICATIONS

Acquiring materials presented no major problems for Johnson, though delivery of some items was slow. Determining the proper heat exchanger to install, however, did present a slight problem. Information on heat exchanger performance at the low temperature levels characteristic of solar heat was not readily available. Another problem was encountered when the Heliotrope thermocouple failed, which resulted in continued circulation of water through the collector after the sun went down. It was repaired by the manufacturer and returned. A few weeks later a lightning-caused power surge put the device out of service again. Although it was easily repaired, Johnson recommends that an inexpensive lightning arrestor be used to protect system components.

Johnson's biggest construction problem was getting paint to adhere to the home's corrugated aluminum roof. Much scraping of the surface and testing of various paints and application techniques was necessary before a black coating could be successfully sprayed on the roof. His experience suggests that using prepainted, preferably flat black roofing would simplify building this type of collector.

Project modifications were few. The size of the tank was reduced from 4,000 to 3,600 gallons to take advantage of a natural rock base discovered when the storage tank ditch was excavated. Placing the exchanger in the cold air return rather than in the warm air duct also represents a deviation from original plans. When Johnson discovered that he had extra Kalwall sheets, he decided to add a 6-by-16-foot greenhouse to the side of the garage. The greenhouse provides some passive heating for the garage.

MATERIAL AND INSTALLATION COSTS

Costs for the Johnson liquid trickle system at 1978 prices are summarized below.

Heat-storage system	$ 982
Circulating pumps and controls	499
Plumbing supplies	317
Heat exchanger	463
Collector coating	100
Collector covering	825
Water treatment system	300
Labor (estimated 480 hours)	961
Miscellaneous expenses	725
TOTAL	$5,172

With the added cost of the garage, which for materials alone cost $3,336, the total project cost $8,508. (The 480 hours of labor includes time spent building the garage.) The aluminum roofing used as the collector absorption surface was already on the house and does not appear as a cost in this calculation.

SYSTEM PERFORMANCE AND ECONOMICS

The 1,400 gallons of propane needed to fuel the furnace in 1978-79 was reduced to 250 gallons in 1979-80. The heat exchanger design appears to be highly efficient, and the cost of electricity for operating the solar components has averaged about 1.5 kWh, for a cost of about $2.25 per month. As late in the year as October 1979, the system was supplying 100 percent of the home's space-heating needs. The Johnsons attribute an average reduction of $10 per month in electricity costs to the domestic hot water preheater. Also, the trickle system has protected the collector from freezing through one winter of operation.

As of June 1980, the Heliotrope thermocouple was still causing problems. Although the company has been very respondent and has continued to repair the device, using manual controls while the thermocouple was out of service has reduced the operational efficiency of the system.

Despite the apparent simplicity of this liquid trickle system, it exhibited some drawbacks that should be mentioned. Because of the large amount of water used for collecting heat and the open nature of the heating circuit loop, it is almost impossible to keep moisture from seeping out of the system in some spots. An inherent problem with using corrugated roofing for the collector surface is that it is often difficult to form airtight and waterproof seals where a corrugated sheet meets a flat surface. Johnson found moisture in the greenhouse sheetrock as well as in sections of his home. Also, wind, sunlight, and precipitation are taking a toll on the wood lath used to hold the collector glazing in place. As a result, the glazing is starting to pull up in spots.

The reduction in propane use from 1,400 to 250 gallons represents a savings of $632 in one year, at $.55 per gallon. Part of this savings certainly is due to a mild winter during the first year of operation. Additional savings of about $8 per month result from using the solar system to preheat domestic hot water.

If total average annual savings were estimated at a conservative $400, the payback period for the investment of $5,172 (without garage) would be less than 13 years. Further years of operation will establish a more definite picture of total annual savings.

Whitefish

Ronald Breese

Ronald Breese was awarded a Renewable Energy Program grant in July 1977. Unlike the other projects in this book, the Breese grant was for solar research and development rather than an application of solar technology. Breese proposed to test and improve a reflective solar collector that could be handmade at a cost competitive with flatplate collectors. Information on the project may be obtained from Breese at P.O. Box 221, Whitefish, MT 59937; telephone 862-5273.

Project Objectives

This project was designed to demonstrate that a handmade reflective collector is not only more effective than a flatplate collector, but that it also is economically viable. Breese maintained that in the northern latitudes of Montana, flatplate collectors are not efficient enough for year-round space and water heating. His ultimate goal was to develop a parabolic concentrating collector that, in an array of 10 to 15 such collectors, could supply most of the space and water heat required by an average home through most of the year.

The general superiority of the parabolic concentrating collector can be attributed to several features, according to Breese. First, a concentrating collector requires less space than a flatplate model because fewer concentrators are needed to supply an equal amount of energy. This feature is particularly critical in Montana, where a large array of flatplate collectors is needed to produce a useful supply of heat. Such large arrays increase building costs and make retrofitting difficult. Secondly, Breese contended, flatplate collectors lose much potential heat through reflection when the sun's rays strike the cover glass at angles less than 60 degrees or more than 120 degrees. This loss increases when two or three sheets of glass are used for insulation, as is often the case because of Montana's climate. Reflective loss can be reduced, with a tracking system that keeps a concentrating collector nearly perpendicular with the sun at all times during the day. Such an automatic tracking system was an integral part of the collector proposed by Breese.

Breese also said heat transfer in a flatplate collector is inefficient. He argued that the transfer of heat from metal absorber plates to pipes and finally to the transfer fluid entails a great deal of heat loss. In the concentrating collector, this loss can be reduced by reflecting light directly on the transfer fluid tubing, thereby eliminating one stage of heat transfer.

SYSTEM COMPONENTS AND OPERATION

Breese's experimental collector was in the shape of a parabolic trough. He modified the collector's slope slightly so that reflected light would be focused onto a strip about 1½ inches wide. Although a true parabolic trough focuses light to a fine line, Breese hoped to show that the wider strip of focused light would heat a large amount of water more rapidly. He also expected the larger width to focus more diffused light, an important capability for collectors to be used in areas where haze and clouds are common.

The collector is framed in wood and insulated with 3½ inches of fiberglass batting. A copper sheet, 4 inches wide, with tubing attached absorbs the focused heat for transfer to an antifreeze solution. Consisting of equal parts of water and antifreeze, the solution is circulated by an electric Teel pump, which moves the 20 gallons of liquid through the collector to a 55-gallon steel drum. The tubing and the drum are heavily insulated with fiberglass to reduce heat loss, which was expected to be significant because these components were outdoors and above ground.

Strips of mirror glass, 1 inch wide, are attached in vertical rows to the inside curve of the collector. The collector is covered with a single sheet of glass. Mounted vertically, it tilts to face the sun during all seasons.

The collector's automatic tracking mechanism is powered by a 12-volt car battery. Solar cells charge the battery, which in turn operates an automobile windshield wiper motor. This motor runs a belt to turn the collector on a single metal axis. Tracking is controlled by another solar cell that starts the motor when it builds up

enough electricity. The tracking speed, set to approximate the path of the sun, is controlled by moderating the electrical flow from the battery to the motor. Breese found that simple 5 ohm resistor provides the desirable reduction of power, moving the collector slightly every three to four minutes.

PROBLEMS AND MODIFICATIONS

Various kinds of solar cells were tested as a part of the project. Because the cells for charging the battery were mounted inside the collector on the copper absorption plate, Breese tried a special solar cell designed to use concentrated light. However, he found that a regular cell using direct, unconcentrated light produced more than twice as much power as the special cells.

The triggering cells to move the collector were located at the bottom of the collector. Initial tests indicated that the light inside the collector was so intense that the motor ran almost constantly during periods of bright sunlight. This problem was solved by placing black blinders on both sides of the triggering cells so that only direct light would trigger the motor.

The upper row of cells produced enough electricity to keep the battery charged and the tracking system operating. Even on hazy days, when a shadow was visible in the collector, the collector continued to track the sun. When conditions were so hazy that no shadow could be seen, the collector would not track. Since little or no heat could be collected under such conditions, however, Breese considered this an insignificant limitation.

The rate of transfer fluid flow through the collectors was a critical variable that Breese tested extensively. A slow rate of flow produced a higher temperature in the fluid, but this gain apparently was offset by more rapid heat loss. After experimenting, he found that a relatively fast flow rate of about 4 gallons per minute was most suitable for gathering heat in the storage tank. With this flow rate, the fluid gains about 1°F with each pass through the collector.

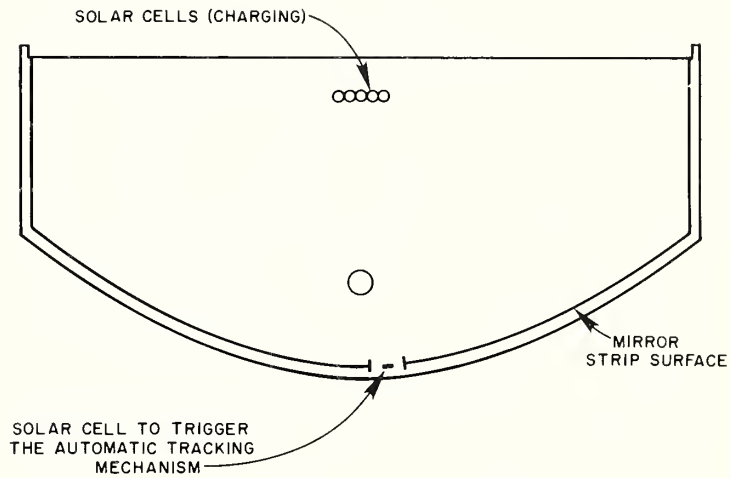
Unfortunately, the complete collector was quite heavy and expensive. Thus, Breese designed a lighter, cheaper model. Clear Kalwall fiberglass, .040 inches thick, was to be used for the cover instead of glass. Slightly thicker fiberglass was to be used for the sides and bottom. The glass mirror strips were to be replaced by light aluminized mylar made by Transilwrap. The mylar is thin, inexpensive, and more reflective than the mirror.

Testing the solar cell triggering device under the Kalwall cover indicated that the light shining through the cover was too diffused, which caused the tracking system to run constantly. This diffused light also was scattered after reflection and could not be focused on the absorption tubes. Clear plastics can, and probably should, be used instead of a fiberglass cover. However, such plastics are expensive at this time.

MATERIAL AND INSTALLATION COSTS

Following is a summary of material costs for construction of one concentrating collector. Labor costs have been excluded, since many hours involved testing and experimentation.

Bearings	$ 8
Pump	64
12-volt motor and belt	17
Plumbing supplies and storage barrel	76
Mirror and glass	51
Hardware	44
Welding supplies	49
Insulation	21
Solar cells	703
Electrical supplies	36
Thermometers	49
Voltmeters	84
Storage battery	133
Miscellaneous	18
TOTAL	$1,352



SYSTEM PERFORMANCE AND ECONOMICS

Although the weight of this collector probably makes its general use undesirable, limited performance data do support the original expectations. Average performance on clear days in the fall of 1978 yielded 233 Btu per hour per square foot of collector. This level of performance

exceeds that attributed to the major commercially made concentrating collection systems, according to Breese. And it clearly surpasses the output range of 105 to 180 Btu per hour per square foot of some flatplate collectors on the market.

Still, after working with the system and testing it under different conditions, Breese concluded that his overall verdict must be negative. Unless high water temperatures are specifically needed, as for direct use in a hot water space-heating system, nontracking collectors should be used. The maintenance cost of a tracking collector makes the system unattractive.

Solar cells also are a questionable investment, according to Breese. It takes more energy to make the cells than they will produce in their lifetime. Until new manufacturing techniques are developed to lower their costs, commercial solar cells are not energy- or cost-effective in a nonremote residential solar-heating system.

William Kilby

In July 1977, a Renewable Energy Program grant of $14,100 was awarded to William Kilby to fund a solar retrofit project at his home in Great Falls. Constructed about 40 years ago, the house had a natural gas fired boiler as the main component of its zoned hot water heating system.

Kilby had several objectives for the project. First he intended to demonstrate a tracking, concentrating collector system in Montana and to show that it is feasible to retrofit such a system to a typical home. Along these lines, Kilby sought to determine whether the concentrating collector was more efficient than a flatplate collector for retrofitting to a hot water heating system. He also wanted to see whether such a system could withstand the extreme temperatures and high winds of Montana.

The public can visit this project by making arrangements with Kilby at 3313 Fifth Avenue N., Great Falls, MT 59401; telephone 453-0973.

SYSTEM COMPONENTS AND OPERATION

The Kilby project represents a highly technological solution to the problem of capturing and using the sun's heat. The system employs 32 concentrating collectors to heat an antifreeze solution that transfers the collected heat to tanks. The concentrating collectors, each with a lens or aperture larger than the absorber surface, focus the sun's rays on a small area. This design makes the solar heat most intense at the point where the solution flows through each collector.

Northrop, Inc. manufactured the 32 collectors, Model MF-NSCP (BC-G)® , which are each 10 feet long and 1 foot wide. The absorbers are copper, and the Fresnel® lens cover is acrylic. The collectors are mounted on a heavy redwood frame located above Kilby's garage and pointed south at a 45-degree angle. Two rows of 16 collectors each were put in place, one row above the other.

The tracking function is controlled by photoelectric cells. Electric motors operate a cable system that moves the collectors in unison to follow the path of the sun. Each collector has its own separate tracking and drive system, but to attain best efficiency, all must move together.

Because of their ability to track the sun and concentrate solar heat, these Northrop collectors can capture more energy per unit area per day than flatplate collectors. In addition, solar heat concentration makes it possible to generate the higher temperature range—140° to 160°F—suitable for an existing hot water heating system. Therefore, the collectors were ideal for this retrofit project.

A closed-loop circuit moves the heat-transfer fluid through the collectors. The 40 gallons of transfer fluid is 50 percent ethylene glycol and 50 percent water, which protects against freezing to -34°F. The solar circuit is protected by a 12-gallon expansion tank that absorbs the expanded fluid if temperatures exceed normal operating levels. A Grundfos No. UPS 26-64F ® pump circulates the solution through a heat exchanger. This exchanger, a Bell and Gossett No. WU66-42® , has a baffle spacing of 2 inches. In this shell-in-tube-type heat exchanger, heat is transferred from the solar circuit to the piped water of the home's hot water heating system. The heated water is pumped into four insulated storage tanks with a combined capacity of 1,000 gallons. Each tank is individually valved so that the system's capacity can be varied according to the solar heat produced on a given day.

Heated water is moved from the garage to the house in pipes buried in a 6-foot trench. The home's existing heating system pump circulates the water to fin-tube radiators for space heating. When a control valve is opened, the solar-heated water enters the conventional gas-fired boiler for additional heating, if required.

Domestic hot water preheating also is provided by the stored water. To ensure that this water will not be contaminated by the antifreeze solution, a shell-in-shell heat exchanger transfers heat from the stored water to the domestic water system. A small Grundfos pump moves the water in this circuit to an American Heliothermal 82-gallon tank. After preheating, the water flows into the existing conventional water heater.

Space heating is controlled automatically by a sophisticated array of electrical devices. A Rho Sigma No. RS106® differential thermostat is set to activate the solar circuit pump when the collector temperature rises 17 °F above the temperature in the storage tank. When this difference drops to 2 °F, the pump shuts off. This temperature range was designed to assure the most efficient use of available solar energy.

A tank sensor by Johnson Controls automatically stops the tracking of the collectors when the highest allowable temperatures are attained. This system can be modified so that one array of collectors will track at a level about 20 °F higher than the others, such as when system capacity is reduced for summer use. Another Johnson Controls device, a pneumatic outdoor-storage rest control, automatically converts the system from solar heat to gas-boiler heat. The lower the outside temperature, the higher the storage temperature must be before switching from one system to another.

A Johnson Controls solar pneumatic valve connected to the solar pump was installed to ensure that the valves are open when the pump is operating and closed when it is not. The device prevents gravity circulation in the solar circuit if the transfer fluid is not sufficiently heated. The control circuitry allows the system to be operated automatically or manually.

PROBLEMS AND MODIFICATIONS

Many problems were encountered in building this system. In addition to the process being delayed by equipment arriving behind schedule, retrofitting required much preparation. Structural mounting frames for the 4,000 pounds of collector equipment had to be built. Also a 6-foot deep trench had to be dug from the garage to the house to accommodate the hot water pipes.

Problems with system components were frequent. The domestic water circulating pump burned out and had to be replaced. Also, the collector tracking system, with its motors and many moving parts, required constant maintenance. Three of the tracking motors failed and had to be replaced. Additionally, two of the collectors leaked fluid when first installed and had to be dismounted and brazed. Because the collectors must be aligned carefully for peak performance, realignment proved necessary after periods of high winds.

A major setback occurred when the system was first operated in February 1978. After only a few hours of test operation, the system had to be stopped for about three days because of subzero temperatures and snow. Gravity circulation of the heat-transfer fluid, which had become very cold, apparently caused the heat exchanger to freeze. Four exchanger tubes split and had to be repaired. The diluted antifreeze solution also had to be replaced at considerable expense.

Commenting generally on the installation problems, Kilby advises that this kind of system be constructed only by an experienced contractor or by someone very familiar with the system. He recommends that the system be carefully designed by experts.

Only relatively minor modifications were made while building this system. Kilby decided to use four 250-gallon storage tanks rather than one 1,000-gallon tank because four tanks provided a more flexible storage capacity. Also, in response to the freezing incident mentioned, Kilby added automatic valves to prevent gravity circulation of the antifreeze solution.

Insulating the storage tanks required some modifications. The original insulation of ½ inch of foamed plastic proved inadequate—any heat collected during the day was lost at night. Also, insulating the garage ceiling made the room too warm for year-round work. The problem was finally solved by housing the four tanks in a box and stuffing about 10 inches of fiberglass insulation around them. This problem emphasizes the importance of adequate storage insulation.

MATERIAL AND INSTALLATION COSTS

Following is a summary of the material costs of the Kilby system:

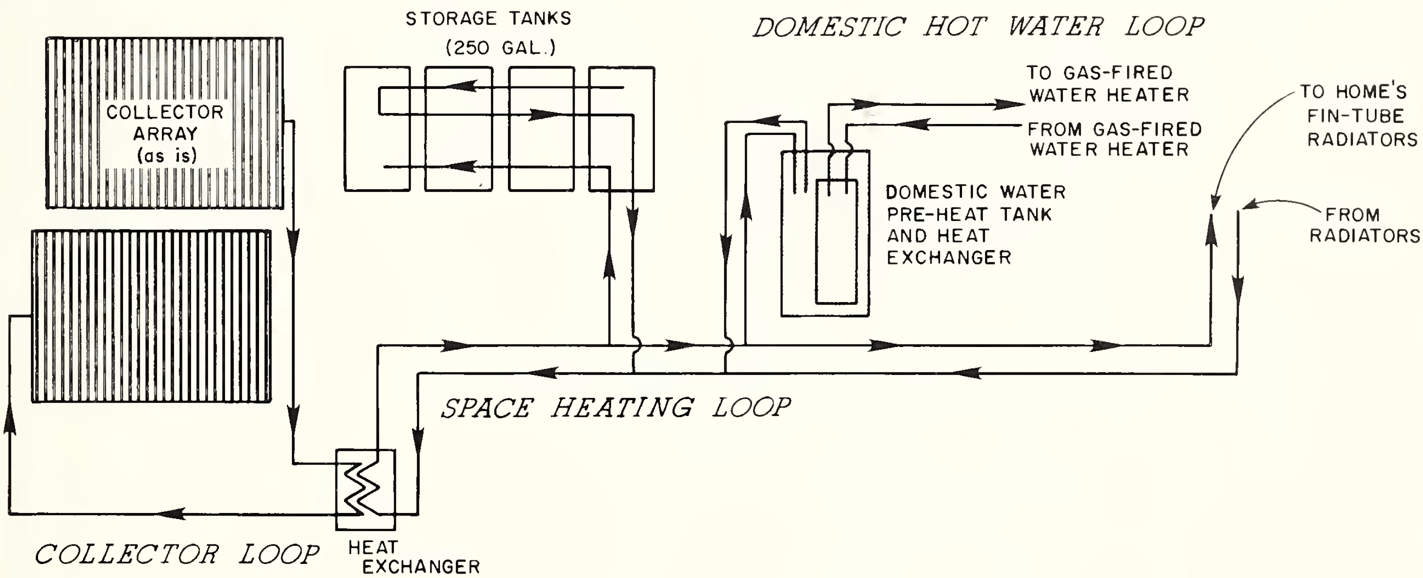
Collectors	$ 6,940
Storage tanks	1,250
Domestic water heater	620
Expansion tank	430
Heat exchanger	450
Insulation	575
Antifreeze (3 fills)	175
Piping, fittings, solder, etc.	2,700
Electrical supplies	100
Pumps	180
Trenching, concrete work	1,000
Controls	125
Personal supplies and materials	200
System design	1,000
Miscellaneous - including donated supplies and other costs	4,979
TOTAL	$20,724

Labor amounted to about 550 hours from the start of the project until it was ready for regular operation in April 1978. No attempt has been made to assign a dollar value to the labor.

SYSTEM PERFORMANCE AND ECONOMICS

Because Kilby has experienced repeated problems with this system, no useful data are available for assessing its long-term performance. However, some general observations can be made. Indications are that the collectors themselves are highly efficient, generating relatively high temperatures in the transfer fluid, but the "0" ring-type connections used by the manufacturer sometimes leaked. If the fluid level drops to a certain point, the circulation pump will not operate and more antifreeze must be added. Kilby hopes to solve this problem by replacing these connections with a more flexible connection.

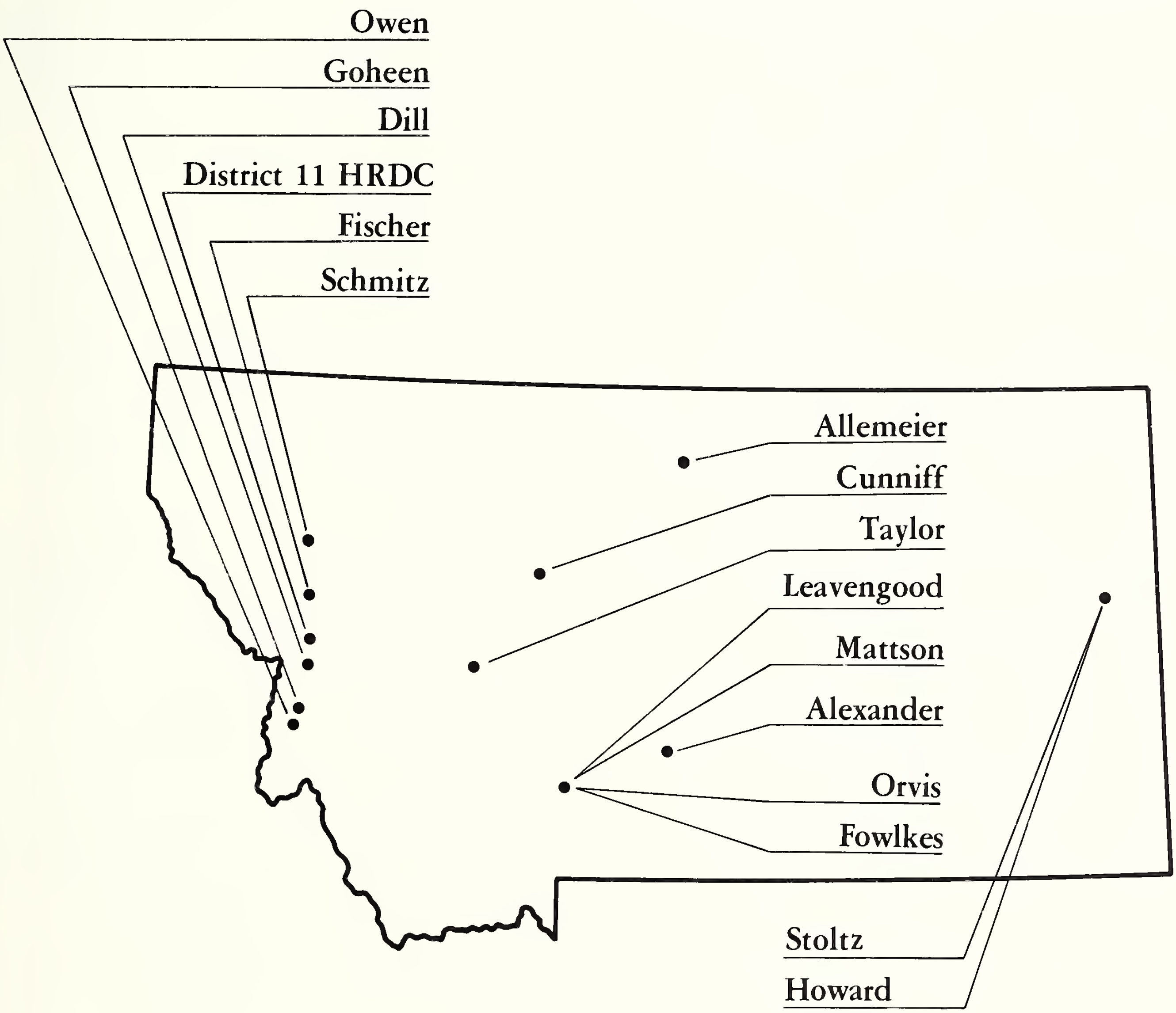
The domestic hot water preheating system also has caused problems. The shell-in-shell-type exchanger used in the system appears to be inefficient, and Kilby does not recommend its use. The preheater tank also developed a leak, which forced the system to be shut down. A detailed analysis of the system, conducted by an independent engineer, is available at the Energy Division, DNRC.



PART II

Active Air Systems

Projects Discussed in Part II



Ronan

Phillip Schmitz

Phillip Schmitz, a Ronan farmer and carpenter, built an active solar space-heating system for his carpentry shop, which he occupies from eight to ten hours per day. The system, financed partially through a Renewable Energy Program grant in 1977, was designed by James Taylor of Helena, whose own project is discussed in this book. Schmitz also built an extremely efficient double-barrel wood stove for backup heating on days when solar gain was low.

SYSTEM COMPONENTS AND OPERATION

Schmitz incorporated the 480-square-foot south wall of his workshop into a vertical air collector. The wall consists of ½-inch sheetrock, painted flat black, mounted on 2-by-6-inch framing and insulated with 6-inch fiberglass batts. The floor consists of 3 inches of concrete on top of 2 inches of rigid foam. The top of the collector is insulated with 6-inch fiberglass batts. The collector panels are glazed with two layers of Kalwall fiberglass, 40-mil on the outside and 20-mil on the inside. The foundation wall that supports the panels is insulated with 2 inches of rigid foam.

A reinforced-concrete rock bin, used to store heat, is located under the shop. The bottom and sides of the bin are insulated with 2 inches of rigid foam; the ceiling is insulated with 12 inches. The bin measures 12-by-10-by-8 feet and contains about 35 square yards of washed rock. Seven-inch concrete walls also can store heat.

Heated air from the collectors can be circulated either into storage or directly into the shop. A regular furnace thermostat with a built-in timer controls a ¾-horsepower fan to circulate air through the system.

Schmitz built his double-barreled wood stove by mounting one oil drum on top of another. The bottom barrel is used as a firebox, the top barrel as a smoke chamber. A brick wall inside the top barrel traps most of the heat escaping from the lower drum. The chimney pipe leaving the upper drum is cool enough to touch when the stove is in full operation.

PROBLEMS AND MODIFICATIONS

Schmitz estimates actual construction and installation time for this system at about two months, although the work was spread out over a longer period of time because he only worked on the system during his spare time.

One installation problem arose after the first load of rocks was dumped into the storage bin. Although the supplier guaranteed that the rocks would be clean, they turned out to be too dirty for use and had to be shoveled out and washed. Also, when motorized dampers in the duct system were found to be leaking air, simple springs were added to the dampers to keep them tightly sealed. In addition, Schmitz modified his original plans by placing 2-by-6-inch studwalls on all the walls of the shop, rather than just the collector wall.

Initial tests showed that the system had the wrong differential temperature control; Schmitz had installed a variable flow controller, used in active liquid systems to start a small motor slowly then increase the pumping capacity as the collector temperature increases. This control was replaced by a constant speed controller designed for active air systems.

Original plans called for a standard commercial wood stove for backup heating. Schmitz decided he could build a more efficient stove at a lower price using the two 55-gallon oil drums. The stove design was modified to create a circuitous path for escaping smoke, thus lessening heat loss. Smoke leaves the lower barrel through an opening at the base of the back wall and enters the upper barrel through an opening in the same position. Smoke must travel over the brick-wall heat baffle, located about 6 inches from the front of the top barrel, before exiting through a flue at the base of the front wall. The stovepipe then makes two 90-degree turns before connecting with the chimney.

MATERIAL AND INSTALLATION COSTS

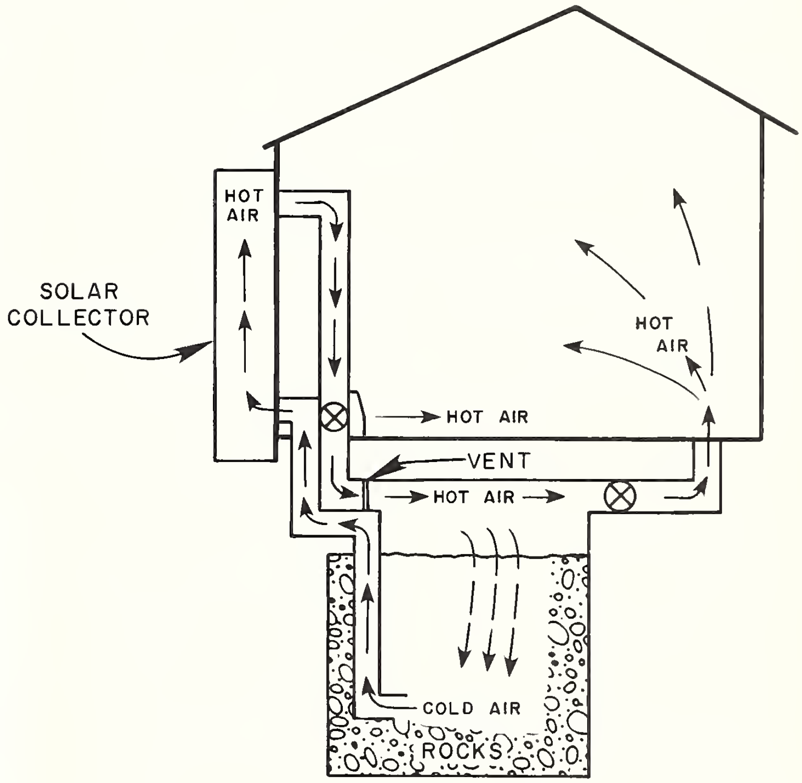
Total cost of the system, at 1980 prices, is listed below:

Solar panels	
concrete—footings and floor	$ 100
insulation—2-inch rigid foam	144
insulation—6-inch batt	192
Kalwall—20-mil and 40-mil	789
glazing, framing, and taping	40
flat black paint	30
collector wall—1/2-inch sheetrock	188
collector trim and caulking	100
Subtotal	$1,547
Rock storage	
concrete—walls and floor	$ 440
insulation—3-inch rigid foam	363
insulation—12-inch ceiling and walls	125
marine plywood sheathing	450
ceiling and wall framing	70
ceiling and wall sheathing	50
rock and block floor trunk line	350
Subtotal	$1,848
Wood stove modifications	$ 250
Air handling equipment	
collector fan	$ 171
storage fan	200
wood stove fan	30
motorized dampers	90
differential controller	125
wood stove limit switch	28
setback thermostat	80
miscellaneous electrical	80
miscellaneous duct work and sheetmetal work	180
Subtotal	$ 984
Engineering and design	$ 450
Monitoring equipment	
electronic thermometer with 11 sensors	$ 205
Miscellaneous additional costs	$ 581
TOTAL	$5,892

In addition to the $5,892 in materials costs, Schmitz estimates that system installation would have cost about $3,340 if labor had not been donated, which raises the total theoretical cost of the system to $9,232.

SYSTEM PERFORMANCE AND ECONOMICS

Between the solar contribution and the heat produced by the wood stove, which consumes about one cord of wood per year, Schmitz estimates savings of $700-$800 per year at 1980 fuel oil prices. This would mean a simple payback period, at fixed oil rates, of about eight years on material costs alone, or about 11 to 12 years if labor costs are added.



Arlee

John Fischer

A second objective of the Jocko Hollow project, mentioned in Part I, was to build an extra room for Cabin B with a relatively large window to allow direct entry of sunlight. This room has a floor area measuring 14 by 16 feet, and a ceiling moderately inclined from the 8-foot peak to the 6-foot eave. Plans were to heat the room and the adjoining house passively. Additional solar heat was to be captured by an air collector and stored in a rock bin. A specially designed wood-burning stove was built into the rock bin to increase storage temperatures. The room was designed for year-round living, and included rock-faced planting beds for growing vegetables.

A unique feature of this project was integrating the collector, the rock storage bin, and the wood stove into one structure. The air collector was built by the grantees from readily available materials. Absorber plates were constructed from scrap sheets of aluminum roofing. Quartered beer cans were riveted to these aluminum sheets to increase the absorption surface area and to create the flow of air needed for best absorption. The entire absorber configuration was painted with flat black, high-temperature paint, to further increase absorption of solar heat. Foil-backed fiberglass insulation, 3½ inches thick, was placed between the absorber plate and the ¾-inch plywood backing.

Solar heat is held in the collector by two layers of glazing; the inner layer is Teflon FEP® film by Dupont, the outer layer is .025-inch Sun-Lite Premium® transparent fiberglass by Kalwall. To protect against heat loss through the collectors, shutters made from 3/8-inch interior plywood were hinged to the front of the collector. These shutters were insulated with 1-inch rigid foam insulation covered with ½-inch exterior plywood. The inside surfaces of the shutters were covered with high-gloss reflective aluminum paint so that when the shutters are open, reflection aids collection.

The collector is mounted at an angle and forms most of the outer wall of the rock heat-storage bin. The bin, with a foundation 2 feet underground, rises to the 6-foot eave, forming one wall of the room. The foundation of both the storage bin and the room consists of 4-inch-thick concrete, insulated on the outside with rigid foam and resting on a polyethylene film vapor barrier. The inside wall of the bin was insulated with another layer of rigid foam covered by ½-inch Celetex Insulboard® wrapped with reflective aluminum foil. The insides of the concrete bin walls below ground level were coated with a waterproofing sealant.

The east and west sides of the storage bin were walled in with 2-by-6-inch framing and ¾-inch plywood. The insides of these walls were insulated with 6 inches of fiberglass and Insulboard® covered by 1-inch rough pine boards. A frame of 2-by-8-inch boards spaced 22½ inches apart supports the main side walls, which consist of plywood lined with compressed fiberglass insulation. Eight inches of fiberglass insulation and a double layer of .025-inch Sun-Lite® fiberglass seal the top of the storage area, which holds 130 cubic feet of 3-inch washed rock.

The interior-facing wall of the storage bin was built with 6-inch cement blocks lined with compressed fiberglass insulation and filled with vermiculite. The blocks were reinforced with rebar and wire mesh. A custom-made wood-burning firebox was installed in the middle of this block wall. The tightly fitting glass fireplace doors are above the room's floor level, and the firebox is seated into the storage rock to allow stove heat to transfer directly to the rock. A layer of asbestos and a layer of sheet metal are directly behind the firebox.

A system of ducts used to circulate air through storage and into the cabin is centered in the storage area. Air can be circulated through the collectors and directly into the storage area, or it can be circulated, via ducts located under the plant beds, directly into the cabin for space heating. Air also can be recirculated from storage through the collector.

Three separate fans circulate the air. The first fan is controlled by a differential Heliotrope® thermostat with one sensor located in the storage area and another in the collector. When air in the collector is 20 °F warmer than air in the storage area, this fan is activated. Hot air is pulled from the top of the collector to the bottom of the rock storage bin when a manually operated damper is closed. If the damper is open, the air will recirculate. The second fan draws air from the collector face or from storage directly into the cabin. The third fan acts as a booster to return cooled air from the cabin to the storage area.

The sun room was designed not only to allow sunlight to enter, but also to hold heat. The lower sections of the east and west walls were doubly insulated by building cement block support walls to form the planter beds. Above the planters, walls were insulated with 6 inches of fiberglass. Small 3-by-8-inch Thermopane® windows were placed in these walls. The planter bed walls, the rock bed walls, and the concrete floor were faced with locally obtained stone to increase heat absorption.

The roof of the room is composed of 2-by-6-inch cedar rafters that support sheets of Kalwall Sun- Lite® fiberglass 48 inches wide. Two layers of this glazing, separated by ½-inch redwood spacers, protect against heat loss. The spacers were notched to permit air to circulate and reduce condensation between the sheets.

A large double-glazed sliding glass door makes up most of the room's north wall, which adjoins the cabin. This door can be opened to allow passively gained heat from the room to enter the cabin, or closed to isolate the room. The door also allows light from the sun room to brighten the cabin's interior, thus reducing the need for electric lighting. The roof of the sun room comes to a peak above the glass door. At the peak, eight 4-by-14-inch vents can be opened, along with larger vents on the east and west walls, to ventilate and cool the room in summer. The vent doors were insulated to reduce heat loss.

PROBLEMS AND MODIFICATIONS

The Fishers are convinced that year-round use of the sun room would best justify this project economically. Original plans had been to isolate the room from the house and make it a greenhouse with many windows. Those plans were modified to integrate the addition with the living space. The sliding glass door became the basis for the new plan. Transparent side walls were replaced by well-insulated conventional walls with small windows. Later monitoring indicated that even the transparent roof surface could have been reduced without sacrificing the sun room concept. The owners planned to install internal shutters so that some ceiling panels can be covered and insulated when heat loss is high.

Another design problem stemmed from locating the collector directly on the rock storage area. The original plan was to increase the efficiency of heat transfer by moving the collected heat only a short distance. However, with such an arrangement heat is lost from storage through the collector. Shutters can reduce this loss, but manually operated shutters also reduce the effectiveness of the system, since they may not be open during periods of limited but useful solar gain. This dilemma might be solved if the storage area were located completely inside the room so that lost heat would contribute to space heating.

A final matter concerns the wood heating system used in conjunction with the rock storage area. After much effort and expense had gone into designing a firebox and having it custom built, the grantees concluded that a conventional wood stove would have performed as well at less cost. The custom burner required adding an extra 8 feet of stove pipe before the stove performed suitably. Another modification entailed connecting the cold air intake duct to the stove. In this way, whenever the stove is hot, incoming air is preheated before it enters the storage bin.

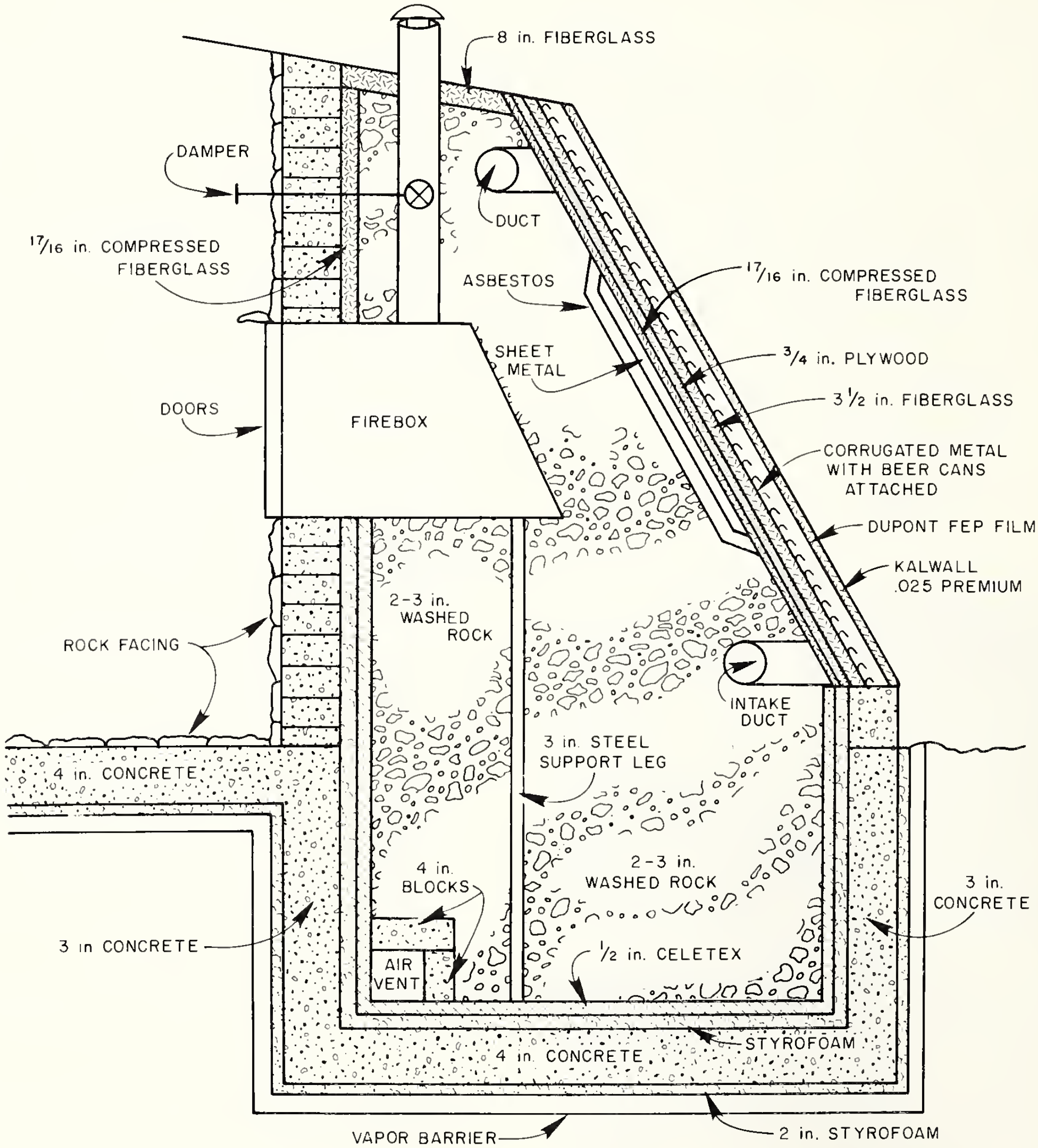
MATERIAL AND INSTALLATION COSTS

The total cost of the sun room, including heating equipment and the structure itself, was $4,815 at 1977 prices. Of this total, $539 was spent for solar equipment, $2,142 for materials, and $2,134 for labor.

The design of the sun room allowed usable living space to be constructed at a cost below the industry average, even when the solar array and insulation costs are included. Because the cabin was small and relatively inexpensive to heat before the project, however, the total savings garnered from the investment will be low. Still, the new system effectively heats about twice as much area as the old system with the same amount of wood. If the planting beds were used to grow vegetables for sale or for the occupants' use, an additional payback would be realized.

The sun room has provided a significant amount of passive heat to the cabin. Even on overcast days when there isn't enough sunlight to activate the air collection system, the room adds heat to the cabin. The light in the sun room also gives the small cabin an open air, while reducing the need for electric light.

Because the Jocko Hollow project included both active air and water heat-collection systems, the grantees reached some comparative conclusions that should be reported. They suggest that because insolation in western Montana is rather limited, solar space heating can provide a significant fraction of the cabin's space-heating needs only in spring and fall. To justify the investment, then, it may be necessary to combine space heating with water preheating, which can take place year round with either solar space-heating system.



Missoula

District 11 HRDC (#1)

In May 1977, $26,875 was awarded to the District 11 Human Resources Development Council (HRDC) in Missoula to retrofit solar space-heating systems to five homes. Because the council's goal was to provide space heating for existing homes owned by low-income clients, it hoped to develop systems that would be relatively inexpensive to build, yet highly effective in reducing utility bills.

The homes chosen for the air collector systems were located in different parts of HRDC's three-county area. For information on the projects, contact the council at 207 East Main, Missoula, MT 59801; telephone 728-3710.

SYSTEM COMPONENTS AND OPERATIONS

Because this project entailed retrofitting active solar systems to five different homes, each system was developed according to the structure and site of a particular home. Also, the installation process varied from house to house as improved techniques were developed. Nevertheless, the basic components and operational designs for the systems were the same. Air was to be heated by rooftop collectors and moved by a fan through ducting down to a rock storage bin. Another fan was positioned to draw air from storage to the living space.

Two different collection designs were used for the five houses. Two homes were equipped with solar panels joined through a series of ports, positioned to create a serpentine flow of air through the collectors. Each panel is divided by a baffle that forces the air to zigzag as it enters at the bottom and exits at the top. This design allows the air to collect as much heat as possible as it moves laterally through the collector. The panels that make up the entire collector array are joined by ducts at the top of the vertically mounted panels.

In the other three homes, the collectors were mounted vertically in two rows, one row immediately above the other. The upper and lower panels were joined with ducts. Portholes cut in the end walls of each panel allow the air to enter the lower panel, pass through ducts into the upper panel, and flow out through an exhaust duct.

All collectors were mounted directly on the roof; thus, the pitch of each home's roof determined the collectors' angle of orientation to the sun. The surface area of the collectors varies from 270 to 340 square feet, according to the heating needs of each home. The warmed air from each panel flows into a 12-by-12-inch fiberglass duct, which serves as a continuous manifold to carry all the collected heat to the main duct and then to the storage bin.

The homes can be cooled through ventilation systems built into each collection system. With these systems, air from the collector is prevented from returning to storage by a motorized damper. When this damper is closed, a motorized shutter is opened to allow the air to escape from the top of the collector to a rotary ventilator mounted on the roof. This ventilator, with the aid of the rising warm air and outside winds, increases the velocity and amount of air drawn from the house, thereby cooling the house.

The collector panels, 36 inches wide and 78 inches long, were framed in rectangular boxes made from Thermax®, a material manufactured by Celatex Corporation designed to resist structural changes at temperatures up to 300 °F. The Thermax is faced with aluminum foil on both sides. The sides and endwalls of the boxes were joined with a spray foam glue made by United Form Corporation. Later, when it became difficult to extract the glue from the cans, the box pieces were joined with 3-inch-wide aluminum tape. The tape seemed to form a bond as strong as the glue.

The insides of the panel boxes were painted with either Nextel® or Solar Components® brand flat black paint. An aluminum absorber plate, also painted flat black, was placed in precut grooves in each box. A bead of clear silicone caulk was applied around the edge of

the plate to prevent moisture from entering. Small ports then were cut in the endwall of each collector to allow air to flow between the lower collector panel and the panel on the roof.

A 2-by-6-inch redwood base was anchored to the roof and 1-by-6-inch boards were nailed in rows down the roof between the redwood boards. The smaller boards were nailed directly to the roof to compensate for the warp and irregularities of the roofing. Holes for the collector inlets and outlets were cut in the roof before the panels were attached to the redwood boards.

Sheets of tempered glass then were placed in precut grooves in the panel boxes and galvanized flashing was placed between each set of collector panels. The panels were bolted to the wood frame and caulked with clear silicone. Workers inside the house, reaching through the previously cut holes in the roof, then cut through the back of each panel. Metal ducts were put into the holes to funnel the warm air into the fiberglass duct and then to storage. The bottom of each collector panel was framed to form a duct manifold for the air returning to the collector.

Warm air and return air ducting was made with Johns-Manville Micro-Aire® duct board, using techniques provided by the manufacturer. The ducting, fabricated at the site, was hung with scrap plastic banding and television antenna wire.

Rock storage bins were built from plywood framed by 2-by-4-inch boards and insulated with 3½-inch-thick fiberglass insulation. The inside wall of each bin was sheathed with ½-inch plywood and lined with sheetrock. To reduce heat loss, the bins' corners were carefully caulked and rigid sheets of insulation board were placed between the cement foundation and the floor of each bin. A plywood baffle was installed to divide the box in two sections. Hollow cinder blocks were laid on the bottom of the box to create a space for air circulation.

The sidewalls of the bin were reinforced with metal banding. Washed rock, ¾ to 1½ inches in diameter, was used for the storage medium. A lid for the bin was constructed from plywood insulated with fiberglass.

Heated air is circulated in different ways within the different houses; a couple of systems employed two fans to circulate this air, while recycled furnace blowers functioned as supply fans for two other systems. The fifth system used a commercial Sun-Grabber® air handler.

Differential controls and thermostats were used to adjust operational modes and heat rooms to desired levels. All the systems operated in conjunction with a supplemental heating source.

PROBLEMS AND MODIFICATIONS

An effort was made to standardize the installation process for these systems in order to make the job easier and faster for the crews assigned to the project. The installation process improved as knowledge and skills were developed among the crews.

Some minor problems developed during system installation. To resolve these problems, the grantees recommend the following: First, collector mounts should be made from redwood, since this wood was found to be consistently straighter than pine. Second, the storage bin joints and lid should be caulked carefully because airtight construction is critical for reducing infiltration and heat loss. Third, storage rock should be washed and shoveled into the bin by hand to prevent dirt from entering the system. Also, for efficient operation, the heat sensor of the differential thermostat should be placed near the bottom of the storage bin, and circulating fans should be properly insulated from the floor and roof joists to avoid noise and vibration.

The fiberboard ductwork used for these projects seems to deserve special mention. Besides helping to reduce the cost of the system, it is light in weight and can be suspended with antenna wire. Also, a variable-speed drill can be used to drive in the self-tapping hex screws, speeding the installation process. Although the ductwork can be constructed easily on site, workers should wear protective masks and clothing to prevent bodily contact with the fibrous material.

Despite the attributes of the ductwork system, there were some drawbacks that also should be mentioned. After several months of operation, the duct tape joining sections of the ductwork began to separate on the collec-

tor manifolds. This was presumably caused by the extreme heat that collected in the manifolds during the summer months. Also, the manifolds leaked a significant amount of air; as a result, they will be replaced with metal ductwork to and from the collector openings. When cool air from the collector began to enter the house through the return air duct, back-draft dampers were installed in the return ducts between the storage box and the roof collectors.

Monitoring of one of these systems by an engineer through a grant from the Renewable Energy Program revealed some serious design deficiencies. Major air leaks occurred through the summer ventilation stack, the ductwork, and the rock storage bin. Also, circulation of air through the storage bin appeared to be impeded by the air baffle; air from the collectors merely passed across the top of the bin and out to the distribution ducts.

Because air was not circulated into storage, little air was returned to the collector from the bin. Instead, since the house return duct was tied into the collector return duct, the collector fan drew air from the house and funneled it into storage. Thus, a portion of the home's heat was lost through the summer ventilation stack on the collector and from the storage bin. These problems created a net loss in space heating during some periods, which may partially explain the increase in utility bills at some of these homes since the system's implementation.

The HRDC staff has reviewed and reevaluated the performence and design of these systems. They plan to modify the systems by completely eliminating rock storage to permit direct solar heating during periods of adequate insolation. At least one of the owners believes that the storage system functions well in his home, and the grantees may decide to leave that system as it is. A better way to seal the summer vent will be developed, and air leaks throughout the system will be identified and sealed.

MATERIAL AND INSTALLATION COSTS

The costs for these five systems, excluding CETA labor, totaled $26,912. Individual system costs ranged from $2,010 to $3,479. Materials costs for the collector panels averaged about $3.50 per square foot of collector area.

SYSTEM PERFORMANCE AND ECONOMICS

Because these systems now are being modified, it is not possible to assess the actual performance or economic return from these systems. The one house that was monitored produced evidence that when the air leaks were sealed and the storage bin redesigned, the collectors could operate at an annual efficiency of 13 percent; this would provide a yearly solar heat fraction of 22 percent.

Missoula

District 11 HRDC (#2)

Developing 12 inexpensive solar space-heating systems for mobile homes was the object of a $26,000 grant awarded to the District 11 Human Resources Development Council (HRDC) in July 1977. HRDC planned to design and build solar air collection systems that were simple and durable, yet inexpensive. The components of the systems were to be built with readily available materials and installed so that the systems could be moved with a mobile home. The systems were built with unskilled labor supplied through the CETA Youth Employment Program. The workers were supervised by HRDC staff.

For information on these systems or to make arrangements to visit any of the homes, contact the District 11 Human Resources Council at 207 E. Main, Missoula, MT 59801; telephone 728-3710.

SYSTEM COMPONENTS AND OPERATION

Because these 12 systems were retrofitted to different homes in separate locations by different people, some variation among the finished projects was inevitable. Nevertheless, the same basic plan was followed for each project. The general methods and materials used are described here.

The system chosen to meet HRDC's objectives features direct solar heating without storage. In this type of a system, the collector is the critical component. Collectors were mounted horizontally on the south walls of the mobile homes, extending from the bottom of the windows to the ground. Each home received four collector panels, mounted side by side on a 2-by-6-inch wooden frame. The collector panels were fastened to the wall with L-shaped steel brackets. The top front of the panels was riveted to the metal siding of the mobile home with metal flashing.

A 4-by-8-foot box made from 1/8-inch tempered masonite board forms the outer shell of each collector panel. An inner insulated shell, formed from Celatex Thermax® hardboard insulation, was placed just inside the masonite outer shell. Thermax® was selected for this use because it is particularly resistant to high temperatures.

Thermax® strips were placed through the Thermax® backing sheet and glued to the masonite board. These strips serve as air baffles that force the air to flow in a serpentine pattern from the top to the bottom and back to the top of each panel. This pattern balances the transfer of heat across each panel. Five baffles were installed in each collector panel.

A .024-gauge aluminum absorber plate was placed on top of the baffles. Both sides of the plate had been painted with flat black, oil base paint. Because heat was to be transferred to the air flowing behind the absorber plate, it seemed necessary to paint both sides of the plate. The collector panels were covered with one sheet of Filon® fiberglass nailed to the collector box with 1-by-2-inch pine strips. The strips keep the surface flat and prevent bubbles or buckles from occurring in the transparent fiberglass covering. Two 6-inch duct holes were cut at each end of the collector box to allow air to circulate from panel to panel.

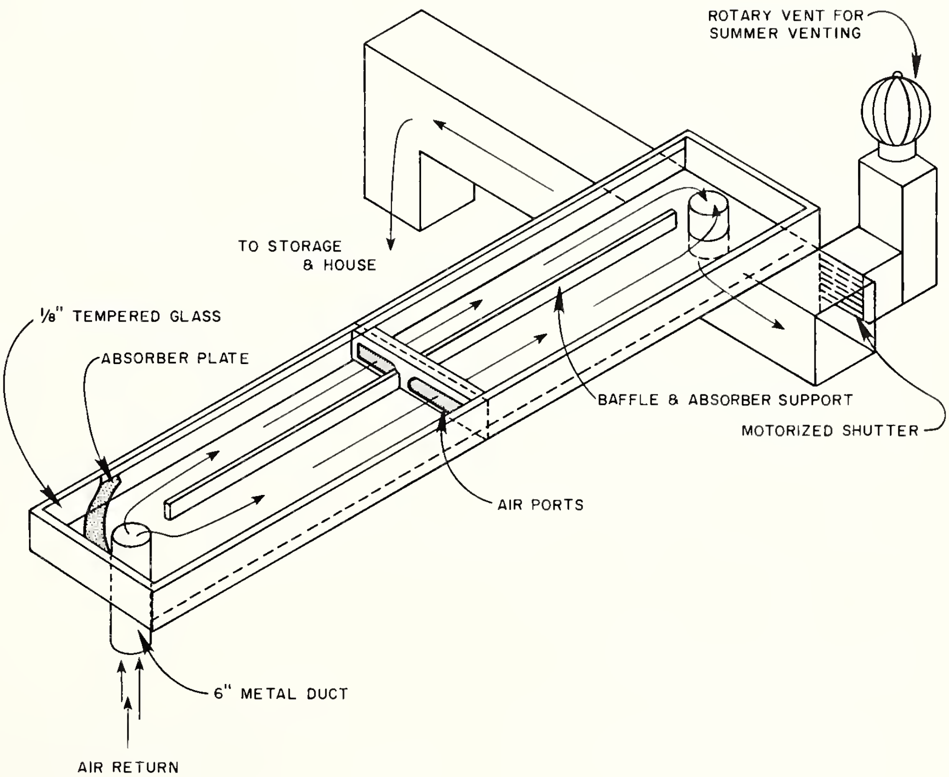
In operation, cool air is drawn from three floor registers along the south wall of the home. Warm solar air enters the living space through two floor registers on the north wall. These registers were built by cutting a hole in the floor, installing a metal sleeve around the holes and riveting a metal boot to the sleeve to hold the register in place. All metal boots, pipes, and air handlers were insulated with fiberglass or 1-inch duct board. The metal boot has a 6-inch circular opening to which an insulated flex duct was connected. The flex ducts, in the crawlspace under the trailer, carry air to and from the collector.

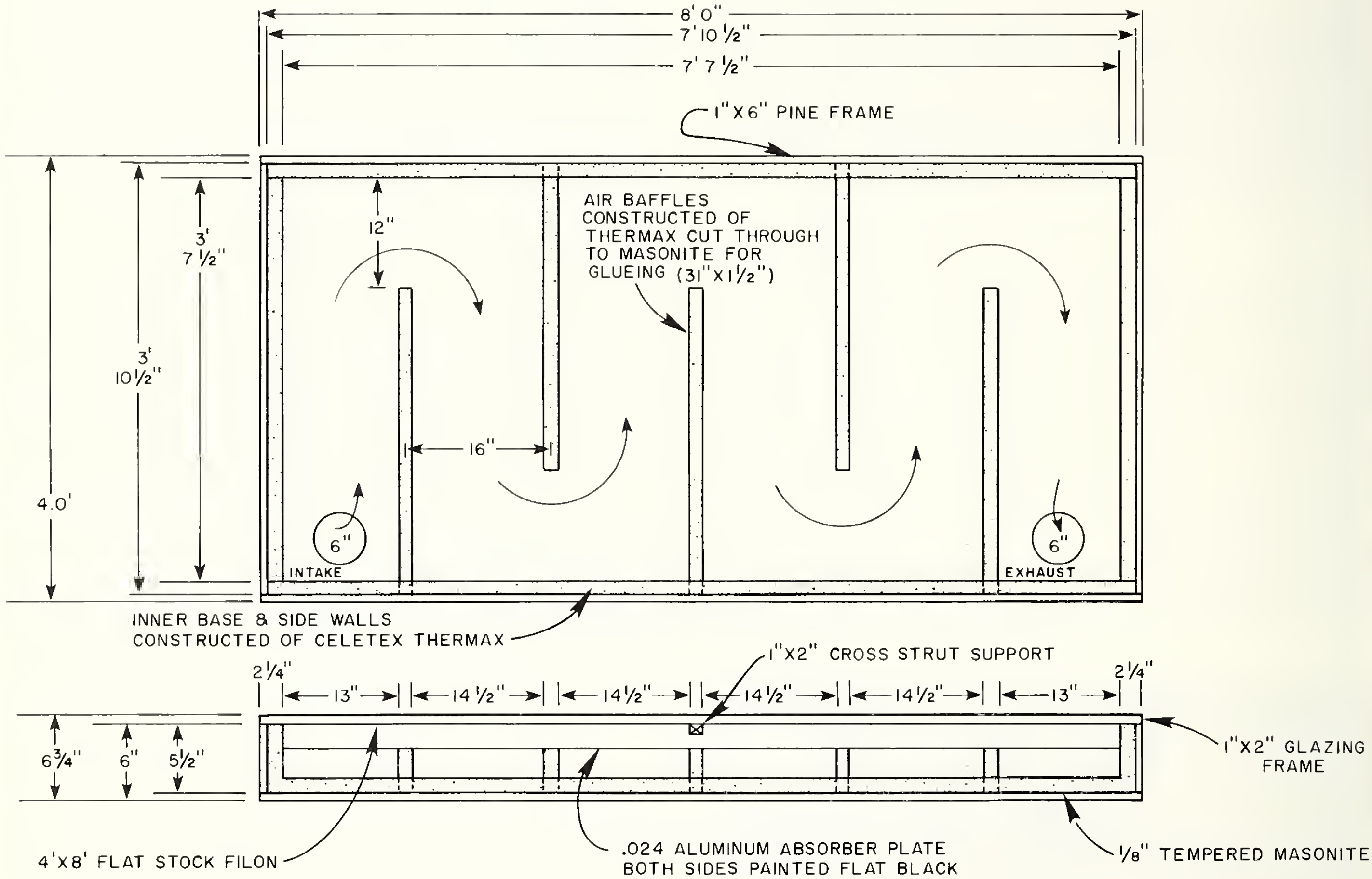
The flow of air is regulated by an air handler contained in a 12-inch-square galvanized metal box. A motorized shutter and a small squirrel-cage fan also are housed in the box. At the signal of the inside thermostat and the remote temperature control bulb in the collector, the shutter opens and the fan is activated. Heated air from the collectors enters through the two main ducts, passes through the air handler and into the hot air ducts on the north side of the home.

Another small fan, with a capacity of 265 cubic feet per minute, was used to assure adequate hot-air circulation. Sweeping air through the collectors too rapidly would transfer heat inefficiently; thus, larger fans were not selected. Large fans required for rapid circulation also are noisy, cause vibration, and use more electricity.

Because the collector cools more quickly than the interior of the mobile home after sunset, a cooling capability was incorporated in this system. A heating and cooling thermostat can be set to start the fan when the collector temperature drops below the temperature inside the mobile home by an established amount.

System controls are mounted on a panel board and include a safety switch, 24-volt transformer, connector box, relay switch, and a Honeywell temperature-control bulb. This design was easily installed and performed better than the special solar control devices available on the market, according to the HRDC grantees. The panel board was located under the home for easy access.





PROBLEMS AND MODIFICATIONS

Although the time required to install these systems varied, eventually a complete operational system could be installed in about one week. Crews of four to six workers prefabricated and installed the systems. Some construction delays occurred because turnover among workers was high, and training new workers slowed progress.

Two fundamental modifications in the original design of this system were made by the grantees. First, an original plan to close off and heat the crawlspace under the home was dropped. The intention had been to heat the entire floor while keeping the plumbing under the home from freezing. An alternative plan to duct the solar heat into the existing furnace distribution

system also was dropped because the grantees believed the arrangement would interfere with furnace operation and complicate the system. The direct-ducted, independent solar-heating system chosen was considered simpler and more efficient.

The second change involved the position of the collector. Originally, the grantees had intended to mount the collector panels on a stand with an attached reflector. This plan was dropped because it would have made more complicated ducting and electrical controls necessary, and because the stand would have been difficult to move with the trailer.

MATERIAL AND INSTALLATION COSTS

The list below summarizes the costs in 1977-78 prices of materials and labor (supplied largely through CETA) for all 12 solar air retrofit systems.

1) Salaries	$12,378
2) Materials	11,304
3) Travel	1,488
4) Administration	1,560
TOTAL	$26,730

The following list represents the average per-system cost of materials used in this project.

1) Collector (4 panels)	$356
2) Air handler	123
3) Air duct system	221
4) Electrical controls	94
5) Paint and preparations	51
6) Supplies	54
TOTAL	$899

SYSTEM PERFORMANCE AND ECONOMICS

After two years of operation, the occupants of these solar-equipped mobile homes remain satisfied with their HRDC systems. The owners report lower heating bills, and their experience seems to confirm the designer's expectations. It is, of course, difficult to generalize about the performance of all 12 systems. HRDC estimates that the solar systems provide from 15 to 50 percent of the space heat needed by the owners annually.

The first retrofitted home, the Nielson project, served as a prototype for the other homes. Performance monitoring done by the HRDC indicates that it has been an unqualified success. Collector efficiency for the Nielson house was placed at 59 percent. The system provides as much as half of the home's heating load in May and September, and 6 to 10 percent of the load during the winter. With this level of performance, HRDC predicts a payback period of 12 years, based on the current price of natural gas.

Independent monitoring in 1980 by a grantee of the Renewable Energy Program returned preliminary reports that were less optimistic. Apparently some systems have been inoperable for significant periods of time. In one case, the flexible ducting under the home had been crushed by dogs that had gotten into the crawlspace. In another instance, monitoring seemed to indicate that the collector fan was removing heated air from the house. These incidents point to the importance of owner involvement in, and understanding of, the solar heating system if top performance is to be achieved and maintained.

Stevensville

Richard Dill

In July 1977, Richard Dill was awarded a grant of $6,361 to develop integrated renewable energy systems and to design, test, and build solar collectors. His objective was to demonstrate that a liquid solar collection system with drain-down freeze protection, operated in conjunction with a wood-burning fireplace and a greenhouse, could effectively heat the space and water for Dill's prefabricated, geodesic home. A large shop-warehouse adjoining the home was to be heated with a barrel stove and air collectors. The focus here will be on Dills' air collector work only.

Dill's home is located 6 miles southeast of Stevensville on a flat benchland known as Sunset Bench. To learn about the project or to visit the site, contact Dill at Rt. 2, Box 50A, Stevensville, MT 59870; telephone 777-3168.

Testing Method

To determine the comparative advantages of different kinds of solar air collectors, Dill undertook extensive testing of six different designs and used the results of the tests to choose the design for the collectors that were to heat his shop. Dill's previous research indicated that the existing solar technology literature commonly supported air collectors over liquid collectors. Air collectors are less expensive to build because they require less material, such as tubing and copper plates, and they can be built from common, inexpensive materials such as recycled aluminum cans or fiberglass.

Air collectors have the added advantage of being easier to build; they can be constructed quickly on a site and require no special technical skills. Air collectors also are said to be more efficient for space heating than a liquid system, which requires some type of heat exchanger, because they can supply heat directly in the form of forced hot air. No freeze protection is required, and they seem to be easier to retrofit to an existing building since they can be mounted vertically on a south wall.

Despite the evident advantages of an air collector system, the debate between the advocates of solar air and solar water collection continues. Dill hoped that testing and constructing a well-designed air collection system, coupled with his previous experience with liquid collectors, would provide a good basis for comparing the two system types.

To conduct his tests, Dill constructed small collector models. Two panel boxes, 2 feet square, were constructed from rigid polystyrene insulation laminated between cardboard. An additional 3½ inches of fiberglass was added inside each box to increase insulation. The sides and back were joined with glue and all seams were sealed by coating the entire inside with fiberglass.

Each box contained an inlet for cool air at the bottom and an outlet for warm air at the top. The two boxes were joined by a manifold so that one fan would supply air to both panel boxes. A vacuum cleaner with reversed suction was used to move air through the collectors. Air entered through the lower right corner and exited from the upper left corner. An effort was made to balance the airflow through each collector by monitoring it with a wind gauge. This would help to ensure that the performance of the different collectors would reflect only the difference in absorber plates and not the volume of airflow. Each box was mounted at a 60-degree angle and oriented toward the south.

Six pieces of particle board were cut to fit into the boxes. Different types of test absorber surfaces were attached to each board. These absorber panels were to be alternately placed in the boxes to determine the most efficient plate design for collecting heat. A layer of 3/16-inch crystal plate glass was secured to the frame of each box with duct tape and nylon strapping. To establish experimental control data, one box was painted flat black and left without an absorber panel so that the effect of each absorber plate design could be isolated.

Test Results

1) Half-can collector— This design is manufactured commercially or can be made by hand. Aluminum cans are cut in half across the middle and attached in a staggered pattern to a wooden backing. The design creates high airflow turbulance while trapping heat in the surface area of the cans. Dill rated this collector as the most difficult to construct but the least expensive. Performance of the half-can model was excellent.

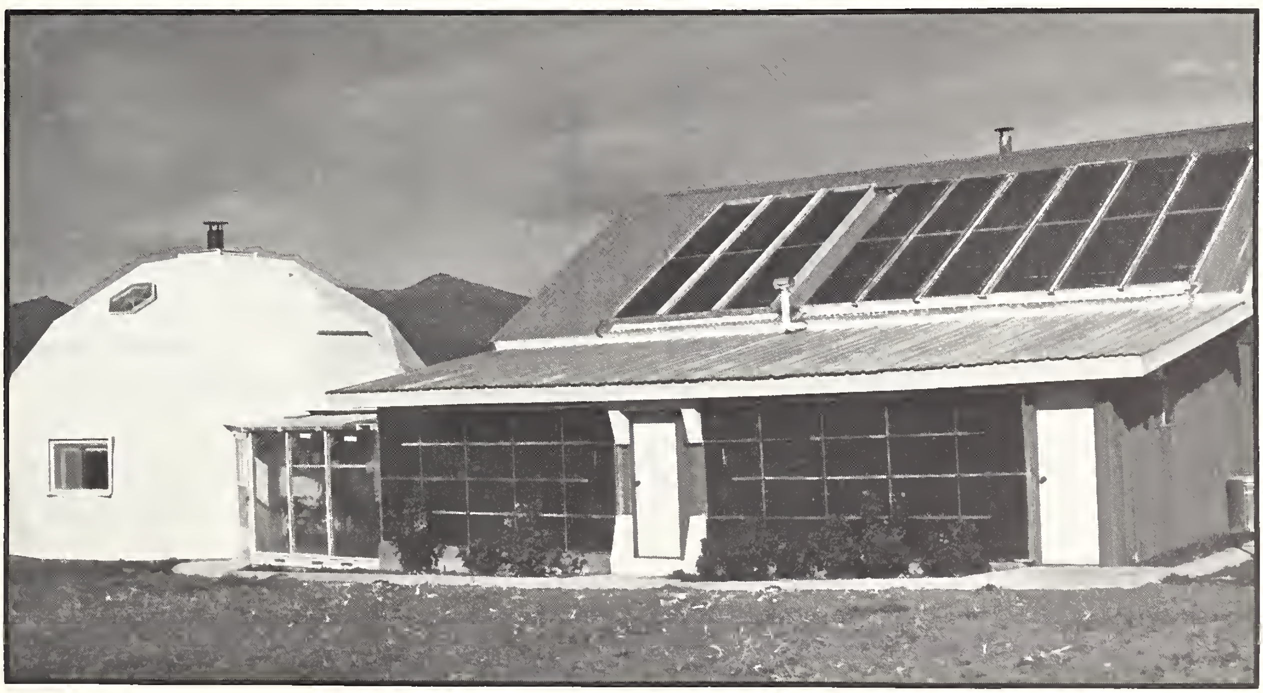
2) Quarter-can collector — For this design, aluminum cans were cut in half and then quartered. The semicircles were stapled to the absorber so that the inner part of the curve faced down toward the incoming, rising air. Air turbulance was high and exceeded that of the half-can collector. Cutting the cans into quarters proved difficult and the risk of getting cut was high. Nevertheless, construction was slightly easier than for the half-can model, while costs of materials were basically the same. Performance of the quarter-can collector was superior to all the other types tested.

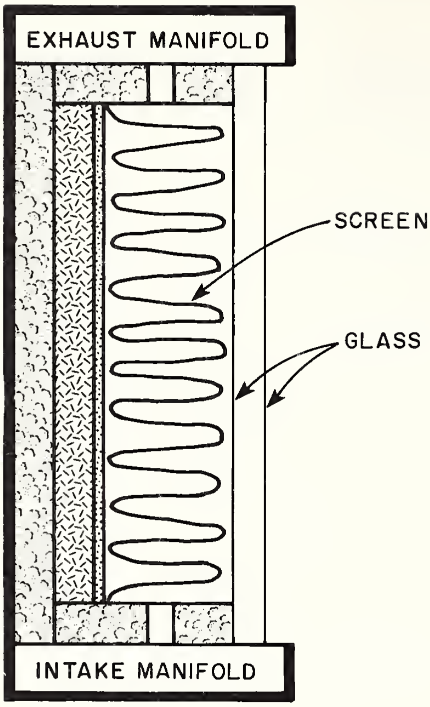
3) Screen collector — In this design, a large amount of surface area is achieved by stapling aluminum screen in loops to the board. About seven loops were attached per foot of panel board. Building the screen collector was simple; Dill rated it as the top design for ease of construction. This collector, however, was relatively expensive and required a lot of material. The screen collector performed about as well as the box without an absorber.

4) Steel-plaster-lathe collector — This model was built from three layers of 10-gauge steel wire mesh. The layers were separated by steel spacers to create a large surface area. Constructing the steel-plaster-lathe absorber was complicated because it was difficult to place the spacers between layers. Dill rated this model behind only the screen collector for ease of construction. Material cost of the steel-plaster-lathe collector was third highest, while performance was a little below that of the box without an absorber.

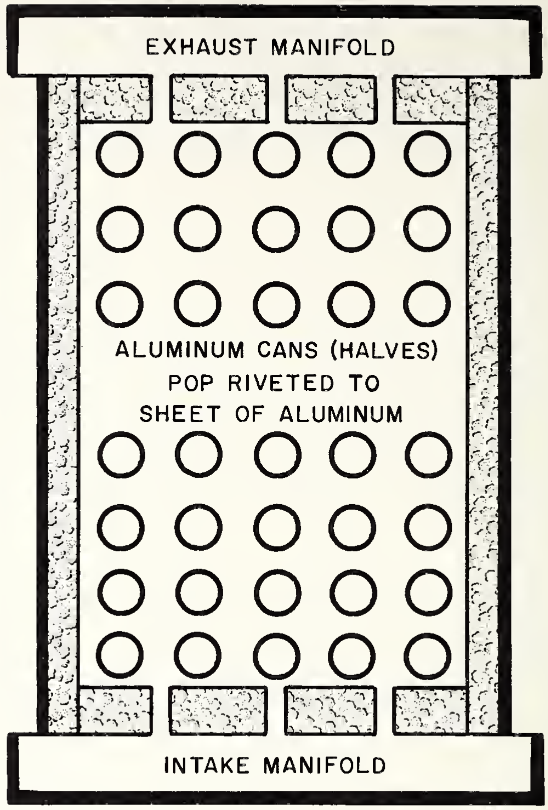
5) Copper collector — For this test, pieces of copper stripping were bent at an angle and stapled to the board. The vertical side of each angle piece was later bent into a fin. The fins then were turned in different directions to create turbulance. The copper collector was rated behind the screen and lathe collectors in ease of construction, and its cost was the highest of the six designs tested. Performance tests showed that the design produced less heat than the control box.

6) Fiberglass wave collector — Since fiberglass is known to be a good heat absorber, the only design problem with this model was to create air turbulance. Rows of curved fiberglass, resembling breaking ocean waves, were formed on the absorber board. This was done by cutting 2-inch PVC pipe in half lengthwise and coating it with vaseline so that a pipe mold could be removed as the fiberglass cured. The waves were spaced 6 inches apart. Holes were drilled in the waves to promote air circulation. Although construction of the wave collector is not complicated, it does require a great deal of time. The cost of this model was low—only slightly higher than the cost of the can collectors. Performance of the wave collector was excellent and ranked just behind the performance of the cut can collectors.

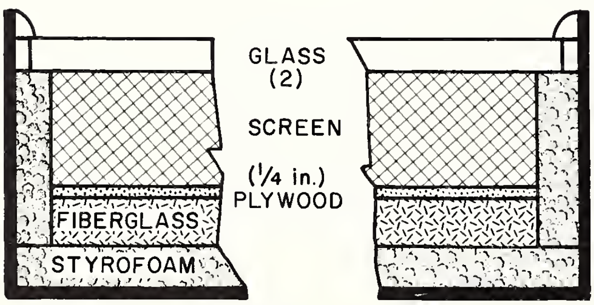




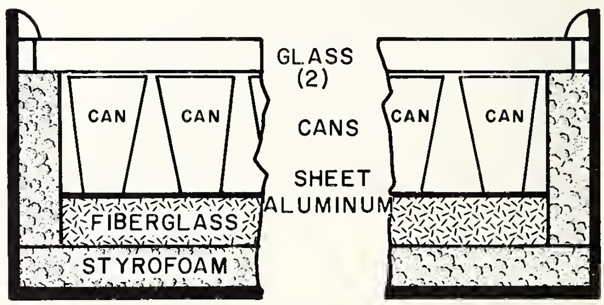
SIDE VIEW



FRONT VIEW



END VIEW-SCREEN



END VIEW-CAN

Dill developed some useful conclusions from these tests. He found that in an air collector, turbulance is more important than either surface area or type of material used. The distance between the collector glass and the absorber surfaces also affects performance. The can collectors and the wave collector absorbers all nearly touched the cover glass, while the other three less effective designs had more space between the glass and the absorber surface.

Dill concluded that the best air collector design includes both high air turbulance and a raised absorber surface area. The fiberglass wave model met both these criteria, and because its performance was superior to that of metals during overcast periods, Dill chose to use this design for his shop.

SYSTEM COMPONENTS AND OPERATION

Fiberglass wave collectors were installed vertically on the south wall of the shop, a project which required extensive modification of the wall. A concrete shelf was poured to support the 216 square feet of collector panels, and custom ductwork was connected through the walls to the collectors. A fan draws air from the shop floor into the intake manifold of the panels and through the collectors for heating. The heated air then exits from the top of the collector to heat the shop. No heat is stored.

The panels were made from fiberglassed polyurethane boards, mounted on the wall in two separate banks of five panels each. The shop ceiling was covered with 6 inches of fiberglass insulation and the walls were insulated with a 2-inch layer of rigid foam sheathed in ½-inch plywood.

PROBLEMS AND MODIFICATIONS

Initial operation of the collector revealed that the wave absorbers created a great deal of airflow resistance. Thus, the waves were removed to leave only a fiberglass box painted black on the inside and covered with glass. Even without an absorber, the fan required a 1/13-horsepower electric motor to push enough air through the collectors to heat the shop. Dill considers this transfer system inefficient compared with a liquid solar collector. He calculated that a similar liquid heat transfer system would require only a 1/35-horsepower motor. This difference is significant, considering that if the shop collectors incorporated rock storage, the additional friction created in the extended loop would demand even more power to move air through the solar circuit.

SYSTEM PERFORMANCE AND ECONOMICS

On a sunny winter day, Dill heats his 900-square-foot shop with a barrel wood stove. When enough heat is being collected in the panels to assist in heating, the fan is activated. When the collectors are operating, shop temperatures can be maintained at about 70 °F without adding more wood. The vertical mount seems to work well. Performance during the heating season is good, while the vertical position helps reduce high temperature air stagnation in the summer. An advantage of Dill's solar air system is that the cost of the fiberglass collector panels is comparatively low. Because the air collectors are used only as a supplemental heating source, Dill hasn't determined payback; savings are limited to the wood not burned on a sunny day.

Corvallis

Stephen and Gail Goheen

Stephen and Gail Goheen were awarded a $5,680 grant through the Renewable Energy Program in July 1978 to build a solar air space-heating component for the heating system of their new home. The Goheens wanted to demonstrate the economic advantages and feasibility of solar heating in the Bitterroot Valley. Much of the planning and construction was to be performed by contracted professionals with assistance from the Goheens. The system featured a simple design so that it could be built inexpensively at the site.

To make arrangements to visit the home or to obtain information about the project, contact the Goheens at NE 1522 Willow Creek Rd., Corvallis, MT 59828; telephone 961-4384.

SYSTEM COMPONENTS AND OPERATIONS

The Goheen's 1,890-square-foot house is insulated to R-30 in the ceilings and to R-19 in the walls. Passive solar heat is gained through 156 square feet of south-facing windows, which can be insulated to a value of R-5 by closing insulated shutters.

Grant funds were used to build a 600-square-foot flatplate solar collector, a 52-cubic-yard rock heat-storage bin, and the necessary ductwork and controls for the solar system. Calculations predicted that the solar-heating component could supply as much as 50 percent of the home's annual heat load. A wood stove, a heat pump, and an electric resistance furnace were to provide backup heating.

Low-cost, on-site construction was a basic design consideration for this system. The collector was built at a cost of about $5 per square foot, without special solar construction skills. The collector is housed in a wood frame, 60 feet long and 10 feet high, tilted at a 60-degree angle and attached at the top to a wooden deck that runs along the south side of the Goheen's house. A wall built from 3/8-inch plywood on a 2-by-6-inch stud frame forms the back of the collector. A layer of 6-inch fiberglass insulation was laid inside the back wall. This wall then was covered with sheets of ½-inch particle board.

Unlike most air collectors, the Goheens' collector contains an air-handling manifold, 10 inches deep, between the back wall and the absorption layer. Two elbow-shaped chambers in the manifold carry warm air away from the top of the collector and distribute cool air along the bottom.

The absorption plate of the collector is separated from the inner manifold by a 3/8-inch layer of black-painted plywood. This outer layer is divided into 30 sections, each 2 feet wide. A hole cut in the bottom of each section supplies cool air to the heat absorption area. Air flows up both sides of the absorber plate to a hole at the top of each section through which it enters the warm air chamber of the manifold. This flow pattern assures an even flow of air and reduces hot spots in the absorber layer.

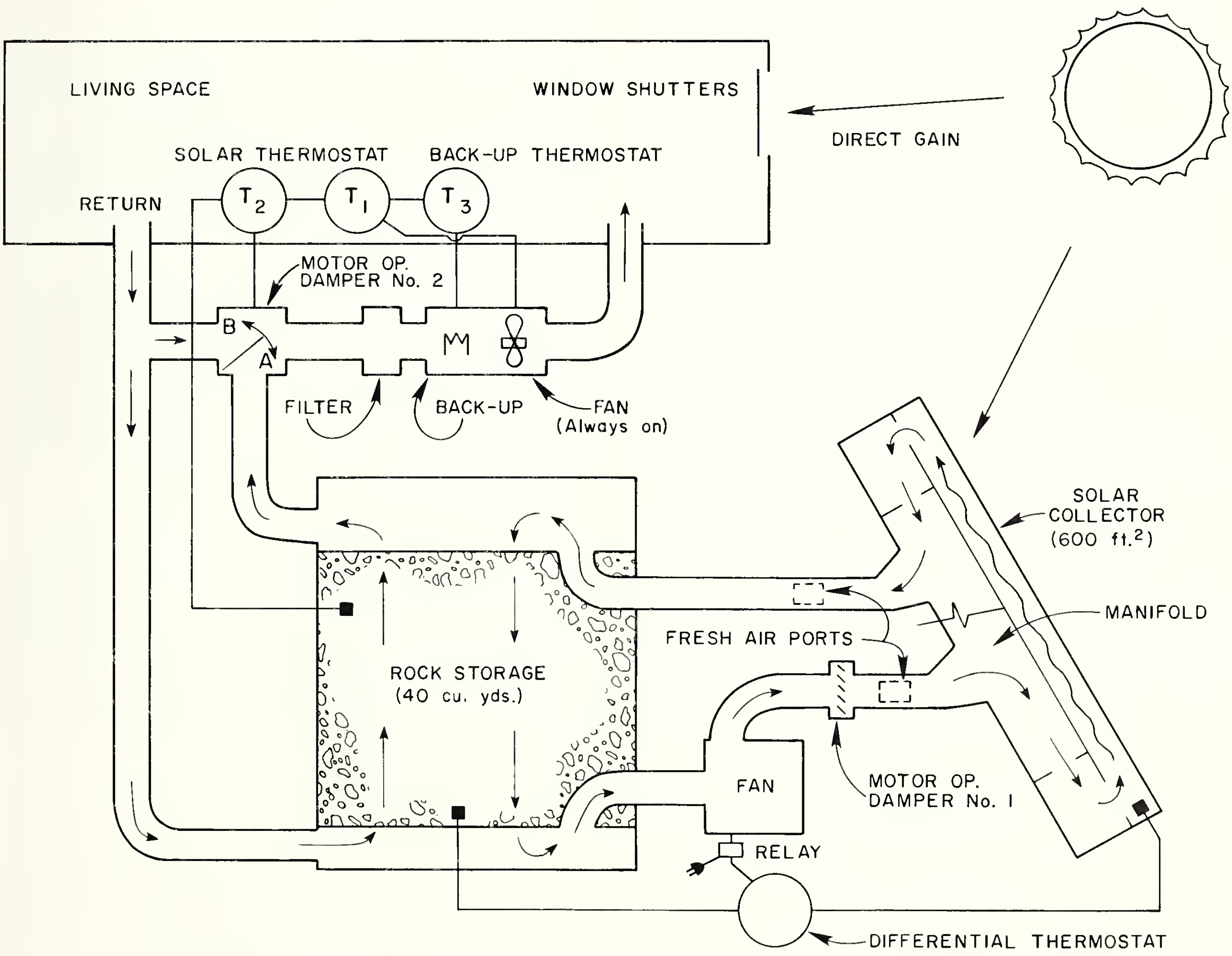
The absorber plate was made from a black-painted metal plasterer's lath, which has a relatively large surface area for efficient heat transfer. An advantage of such a low-mass, high-surface-area absorption medium is that it can collect solar heat during brief periods of sunshine, such as on partly cloudy days. The rough edges of the lath agitate the air flowing on both sides of the plate, thus enhancing heat transfer. One layer of Kalwall Sun-Lite Premium II® covers the collector. The cover and wooden joints of the collector frame were sealed with caulking.

Rocks for heat storage are contained in a 12-by-13-by-9-foot bin in the basement of the house. Locating the bin in the basement allows any lost heat to warm the over-lying living space. The bin floor was formed from a 4-inch concrete slab; rigid foam insulation was placed between the slab and the ground. The foundation wall, bermed and insulated to prevent heat loss, forms one side of the bin. The other three walls are insulated plywood. The entire bin was wrapped in polyethylene to keep moisture out. A series of tie wires between opposing walls counters the outward pressure exerted by the weight of the rocks.

Airflow manifolds were installed in the top and bottom of the bin by placing 2-by-4-inch boards on top of cinderblocks. Both manifolds were laid out in the same direction to assure an even flow of air through storage. The bin was filled with 40 cubic yards of 1½-to-4-inch washed rock deemed unusable by a concrete company. Cool air flows through a duct into the bottom of the bin where it can be circulated up through the bin to collect stored heat or drawn into the internal manifold of the collector. All collector-warmed air enters the top of the bin to heat the rocks.

Three thermostats control the furnace fan, a motorized damper, and an electric heater to automatically heat the home. In operation, the system draws heat from storage if the rocks are sufficiently hot, or bypasses them if they are not. With the controls set for normal operation, the heat pump provides direct heating during the day, while stored solar heat is circulated into the home at night.

Thermostat 1 senses temperatures in the living area and activates the main furnace distribution fan and thermostat 2. Thermostat 2 monitors rock storage temperature and, if temperatures are high enough, opens a motorized damper to circulate air through storage. If storage heat is inadequate, the air will simply flow back to the electric furnace for reheating. A second stage of thermostat 1 is set to active thermostat 3 if the temperature in the home falls 2°F below the desired level. When activated, thermostat 3 starts the heat pump and the electric furnace. The thermostats are set to ensure that the home is heated first by passive gain or wood stove heat, then by stored solar heat, and finally by electric heat.



The solar collector circuit is operated by a differential thermostat that compares the absorber temperature to the storage temperature. A fan is activated when heat can be gained in storage. A motorized damper prevents losing heat through the collector when heat cannot be gained.

PROBLEMS AND MODIFICATIONS

Constructing this system was straightforward and simple, according to the Goheens. The entire duct system, including controls and thermostats, was installed by a heating contractor. The only major problem the contractor encountered involved adapting the thermostats to the solar storage circuit while maintaining automatic operation of the heat pump and electric furnace. An extra relay was introduced into the fan circuit and an extra cut-off switch installed so that thermostat 1 could be shut off manually. The Goheens believe that adding lights to indicate which heat source is being used would allow the system to be monitored more effectively.

Preparing and filling the bin with storage rock also presented a problem. The Goheens believed that the rocks should be as clean as possible to avoid filling the collector with dust. Sprinkling the rocks with water proved ineffective, so the grantees were forced to wash the rock by the bucketful before placing it in the bin. After filling the bin, the rock was blown dry before sealing the bin with an insulated wooden lid. This process required much time and effort. In retrospect, the Goheens suggest that the effort may not have been necessary.

Due to the intense heat trapped in the collector, the fiberglass glazing buckled and developed waves, breaking the collector seal. Caulking was applied to reseal the cover.

If they were to build their system again, the Goheens would consider building the collector directly into the south wall of the home. This design, however, would interfere with the view and affect living space in a way that the existing deck-supported collector does not. Costs would be reduced by eliminating the support wall on the back of the collector and by shortening the duct runs to and from storage. Efficiency also could be enhanced with such a modificaton, since heat lost through the back of the collector would contribute to space heating. Shorter duct runs also would reduce the amount of heat lost while moving the heat from the collector to storage.

MATERIAL AND INSTALLATION COSTS

The following list summarizes the material and installation costs (1978 prices) of the Goheens' solar heating system:

1) Storage bin materials	$ 796
2) Collector materials	2,344
3) Ducting and controls	350
4) Contracted labor	1,610
5) Other labor	
(approximately 212 hrs)	1,820
TOTAL	$6,920

SYSTEM PERFORMANCE AND ECONOMICS

Overall performance of the Goheens' system has been good. After a sunny winter day, temperatures in rock storage are in the 100°F range. Most of this heat is exhausted by the next morning, however, so unless the sun shines the following day, the solar contribution sharply declines. During the spring, storage temperatures reach 130° to 140°F and, thus, provide a longer solar heating period.

In the six-month heating season from November 1979 to May 1980, the solar system supplied an estimated 31 million Btu of the home's 62 million Btu heating demand. This performance matches the 50 percent solar heat fraction theoretically calculated for the system, although it had been predicted that 47 million Btu might be produced by the solar array.

With performance near the expected level, the predicted savings of $296 per year would mean a payback period of 23 years. Actual performance indicates that the payback period may be longer. Nevertheless, the highest 1979-80 monthly electric bill for this relatively large house was only $42, of which about $22 was for space heating. The only other heating cost was the price of two cords of wood used for backup heating.

Hamilton

Gail Owen

Part of the $12,262 grant awarded to Gail Owen in November 1976 (see Part I of this volume for a description of Owen's active liquid system) was for demonstrating solar space heating with flatplate air collectors. The collectors were intended to provide space heating for Owen's 1,377-square-foot home in the Bitterroot Valley north of Hamilton. The complete project can be viewed by making arrangements with Owen at 363-2549.

SYSTEM COMPONENTS AND OPERATION

The Owens' solar space-heating system consists of three main components: a flatplate air collector, a heat pump, and good insulation. While Owen expected that an auxiliary heating source would be necessary, his initial data indicated that as much as 82 percent of the home's space-heating requirement could be met with this combination of heat collection and conservation. The system is considered to be "non site-specific"; i.e., as long as the house is exposed to the south and sunlight is available, this kind of system could be expected to produce a similar solar-heating fraction on any site.

A basic premise of this system is that extensive efforts must be made to conserve heat after it has been captured and distributed. As a result, the finished home is a good example of what can be achieved with proper insulation.

Exterior walls were framed with 2-by-6-inch studs spaced 24 inches apart. Foil-faced fiberglass insulating batts were laid in a layer 6 inches thick under all floors of the one-story home to provide an insulation value of R-19. The walls also were insulated with 6 inches of fiberglass, the ceilings with 12 inches.

Triple-glazed thermal windows were installed to reduce heat loss. Also, the proposed wooden doors were replaced by metal doors with a core of polyurethane insulation. These doors are equipped with a magnetic seal that is nearly as effective as those used to seal refrigerator doors. All structural openings were weatherstripped or caulked with latex or similar materials.

A commercially made collector was chosen for this system. The Sunglow Model 96® by Champion Mobile Homes has an absorber plate of finned aluminum, which was painted flat black to increase heat absorption and covered with two layers of glass to hold the absorbed heat. Total surface area of the collector is 96 square feet. Collection is increased through 96 square feet of reflective surface, mounted on the back of the collector's hinged shutter.

The collector is mounted at a 60-degree angle in a triangular structure 15 feet from the side of the house. This structure, consisting of plywood backed with rigid foam insulation, rests on top of a rock storage bin. This design, known as a solar furnace, includes internal airflow baffles that regulate the flow of heated air from the collector to storage. An electric fan circulates the air to storage and then into an insulated duct. This duct subsequently carries the warm air underground into the home's forced-air heating duct system and returns cooled air to the solar furnace. About 250 pounds of rock storage was provided for each square foot of storage space.

A General Electric Weathertron® heat pump, with an indoor and an outdoor unit, is the third main component of the system. The indoor unit includes an electric resistance heating unit that provides additional heat for the system. This system maintains the desired living space temperatures automatically through thermostatic controls.

All ductwork is located in a crawlspace under the home. The duct network consists of a large hot air trunkline and a smaller cold air return. A bypass system in the ductwork was devised by installing gravity-operated and fan-powered louvers to flush the solar furnace heat directly into the forced-air system when solar input is high.

This system has two basic modes of operation. In the normal mode, when air in the solar storage unit is above

90 °F, electric controls activate the distribution fan in the solar furnace. At the same time, the indoor unit of the heat pump begins fan circulation.

When solar input for direct heating is insufficient, the second mode begins automatically. If solar storage air is between 75 ° and 90 °F, the outdoor heat pump compressor and intake fan are activated to capture latent atmospheric heat and deliver it via the pump's indoor unit to the home's living space. When temperatures in storage drop below 75 °F, three fan-powered louvers and four gravity-operated louvers are closed to bypass the solar heater completely. Only when demand outstrips supply will the supplemental electric resistance heater be used.

PROBLEMS AND MODIFICATIONS

No major problems or revisions were encountered in building this system. However, several small changes had to be made in the original plans. Although the construction phase was relatively short, later modifications proved time consuming. Lack of a basement made installing the ductwork difficult and slow. Also, hand-loading the solar storage bin with 25,000 pounds of rock was particularly tedious, according to Owen.

Much time was lost when the Sunglow® collectors arrived with inlets and outlets in different positions than advertised. This made design changes necessary. Further complications arose because incorrect color-coding was used on the main differential control of the solar air heater. System operation was delayed for several weeks before the error was discovered and corrected.

Two other electrical problems also impeded system implementation. A switching center for the electric control system had been located inside the house, but its operation was so noisy that the entire unit had to be rewired under the house. Also, the household lights flickered whenever the heat pump was activated. Efforts to resolve the problem, which included consulting the utility company, proved fruitless and the problem still exists. The complex duct system, with its fans, louvers, and 42 dampers, also required testing and modification. Heat distribution was often disproportionate among the many outlets and had to be equalized by attaching weights to one louver, eliminating one fan, and changing the main indoor blower fan from two speeds to one of continuous rotation. Although continuous circulation consumes extra electrical power, it generally succeeds in maintaining comfortable room temperatures.

After the first two years of operation, accumulated moisture in the attic remains a problem. Because the vapor barrier between the living space and the attic is inadequate, any warm air escaping to the attic rapidly cools and moisture condenses on the underside of the roof. The solution to this problem, caused by the thick insulation, Owen says, is increased attic ventilation.

Some features of the system simplified its installation. Fiberglass ducting was less expensive and easier to install than metal or wood, and it produced better air distribution in a quiet, leak-proof manner. Also, simple color-coding made the complex electrical controls relatively easy to install. Finally, using 2-by-6-inch boards rather than the usual 2-by-4s for the house frame proved to be a cost-saving feature by allowing room for 6 inches of wall insulation.

MATERIAL AND INSTALLATION COSTS

The following list summarizes the costs of materials and installation of Owen's solar air-heating system at 1977 prices. Labor costs were computed at the rate of $7.50 per hour.

1) Air Heating	
Equipment and structure	$ 3,550
Labor	1,500
2) Ducting	
Equipment and structure	1,210
Labor	3,000
3) Insulation	
Equipment and structure	3,930
Labor	2,500
4) Electrical	
Equipment and structure	700
Labor	3,500
5) Administration and other	4,190
TOTAL	$24,080

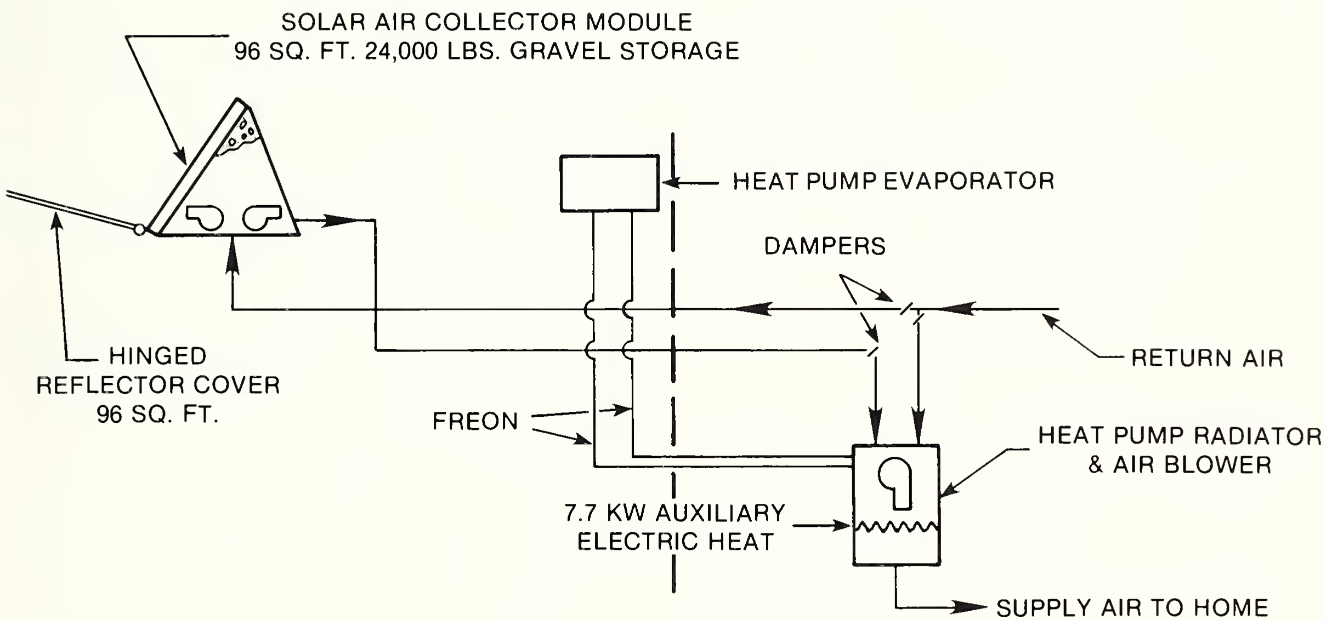
This total does not include the cost of the solar domestic hot water system described in Part 1 of this volume.

SYSTEM PERFORMANCE AND ECONOMICS

Although the insulation and heat pump components of this system have performed at least as well as expected, the solar component has not performed at the anticipated level. Owen carefully evaluated the performance deficiencies during the first year of operation to identify the source of the failure. After a second year of operation, from 1978 to 1979, he concluded that the collectors could not perform at their advertised level. Owen suggests that a much large collector surface area might bring the solar contribution up to levels that would justify system installation. Also, the collector's performance was especially poor in warmer weather. When outside temperatures rose to about 40 °F (rather than the 55 °F temperature advertised by the manufacturer) the collector lost Btu output dramatically.

The heat pump, on the other hand, increased heat output significantly as temperatures rose above 40 °F. The pump alone has supplied as much as half of the home's annual heat load. Indeed, the performance of the heat pump in the system surpassed that of the collector by such a margin that Owen believes it may be the most feasible way to use solar heat in western Montana.

Owen is satisfied that the system is less costly to operate than a conventional fossil fuel heating system. Annual heating costs for 1978-79, which included a harsh winter, were about $325. This cost was less than the annual costs paid by Owen in his previous, comparably sized home in 1975-76. Total annual savings for 1977-78, when winter temperatures were more moderate, were even greater. If savings gained by the domestic solar hot water system are included, the project saved about $185 in energy costs during that year.



Havre

John Allemeier

In 1978, John Allemeier of Havre began work on an active solar space and domestic hot water heating system to demonstrate the feasibility of homemade collectors and owner-designed systems. Because his project was financed partially through a $6,309 Renewable Energy Program grant, it can be visited by the public. For appointments, contact Allemeier at Simpson Route, Havre, MT 59501; telephone 265-2949.

SYSTEM COMPONENTS AND OPERATION

Allemeier's 360-square-foot solar collector employs aluminum printing plates to absorb heat. The collector was insulated with 2 inches of rigid foam, backed with ½-inch plywood, and double-glazed with fiberglass Filon® . To increase heat absorption, Allemeier attached scrap metal shavings to the printing plates. According to previous tests conducted by the grantee, this process increased collector efficiency by about 25 percent.

Heated air from the collector can be ducted directly to the house or through a rock heat-storage bin under the garage. The bin is insulated from the ground with 2 inches of urethane, ½-inch particle board, and a double layer of black, waterproof plastic. The duct system into the home is insulated with 3½ inches of fiberglass. The hot air and return air ducts are separated by 1 inch of rigid foam insulation to further reduce heat loss. Also, all exposed air ducts behind the collector are wrapped with 3½ inches of fiberglass insulation.

A hot water preheating tank, located inside the rock storage bin, is connected to the conventional water heater with ½-inch copper pipe. Manually operated gate valves in the line allow the system to be shut down in an emergency. A separate, insulated rock bin acts as a cooling mass during the summer.

PROBLEMS AND MODIFICATIONS

Although Allemeier was able to obtain most of his construction materials locally, he did have difficulty finding a supply of washed rocks suitable for thermal storage. The rocks he purchased from area suppliers were mixed with clay and dirt and had to be washed by hand before they were clean enough for use.

Allemeier also encountered a problem in obtaining concrete forms from local contractors to construct the rock bins. As a result, Allemeier made the forms out of plywood; he later used these forms to construct the solar collectors.

Allemeier chose not to insulate the top of the rock bin as originally intended. Instead, heat lost from the storage bin goes directly into the slab floor and, thus, contributes to garage heating.

MATERIAL AND INSTALLATION COSTS

The following costs, at 1979-80 prices, represent the grant expenditures for the system:

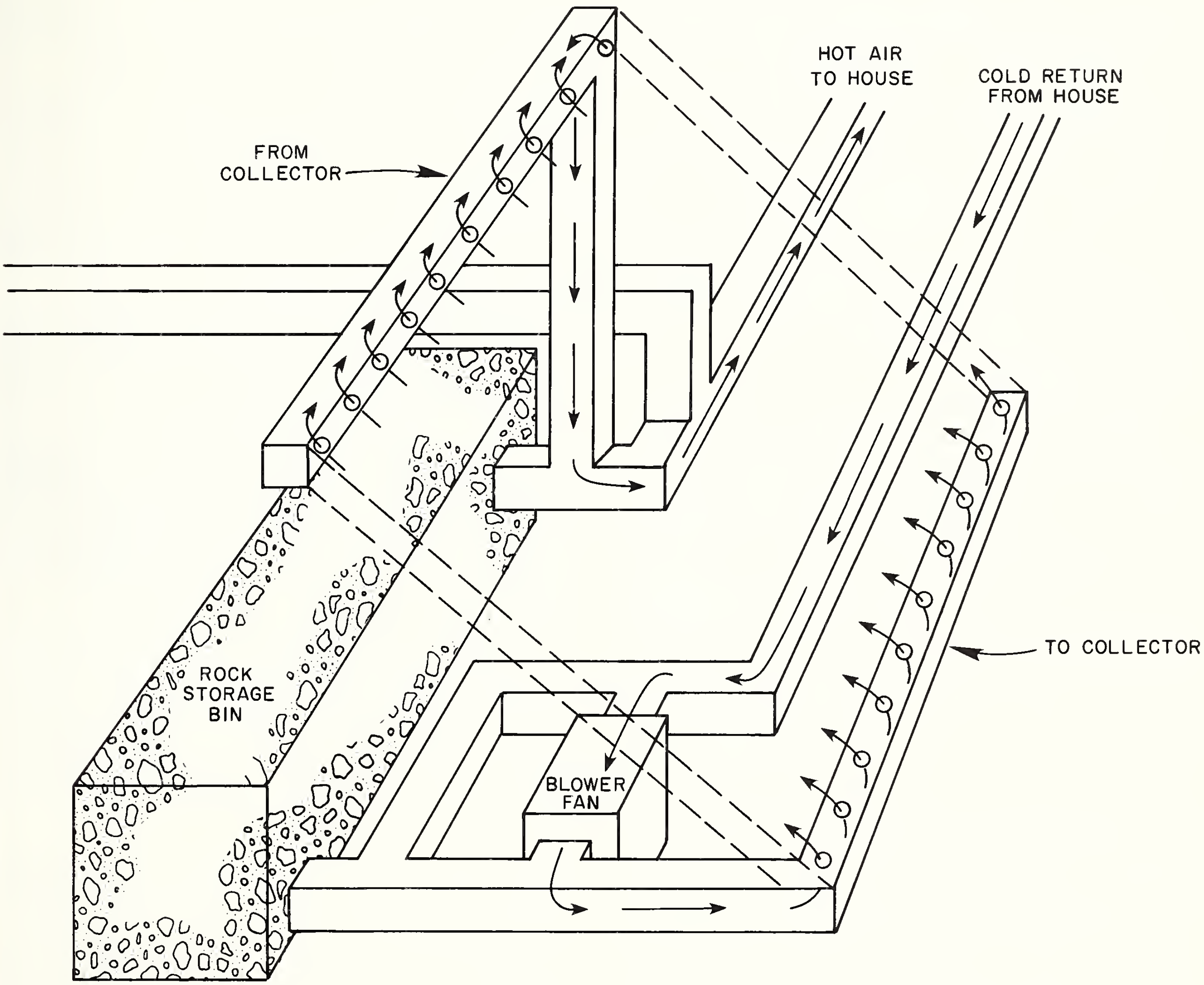
Excavation	$ 225
Concrete/cement	1,257
Lumber	2,657
Rocks	86
Copper fittings and material	103
Insulation	240
Fiberglass Filon®	411
Controls	146
Miscellaneous material	631
Equipment rental	25
Labor	528
TOTAL	$6,309

In addition to these costs, Allemeier donated a great deal of his own time and labor, some damper motors, small hardware, and approximately $1,025 in cash. Allemeier figures total system cost at $7,634.

SYSTEM PERFORMANCE AND ECONOMICS

Although this system has not been monitored in detail, Allemeier estimates that it provides approximately 85 percent of his home's heating and cooling needs. Much of this is undoubtedly due to the fact that the home is extremely well insulated. At 1980 prices, this represents a savings of approximately $876 per year, for a simple payback period of 9 years.

Although heat lost from rock storage is used to heat the concrete floor of the garage, this loss reduces the amount of heat that can be used to warm the house. Unlike the rest of the well-insulated home, the garage suffers from infiltration of cold air and a lack of adequate insulation. Because the rock bin is located under the slab floor, it would be very difficult to add insulation now, although doing so surely would increase system efficiency.



Great Falls

Gregory Cunniff

Gregory Cunniff was awarded a Renewable Energy Program grant of $16,850 in July 1977 to demonstrate the feasibility of retrofitting an existing house with a combination wood and solar space-heating system. He expected this system to meet about 85 percent of the annual space-heating needs of his home, located on the north side of Great Falls. Additional heating was to be provided by a conventional natural gas furnace.

For information on the project or to make arrangements for a visit, contact Cunniff at 742-33 B Ave. N.E., Great Falls, MT 59404; telephone 761-0606.

SYSTEM COMPONENTS AND OPERATION

A primary concern in this project was to employ commercially available solar technology with little or no dependence on "do-it-yourself" labor, technology, and planning. Cunniff maintained that because most people are neither able nor willing to build their own solar systems, the availability and usefullness of commercial systems must be tested. The project was planned by a professional engineering firm and most of the labor was performed by building contractors. Cuniff hoped to show that with the planned integration of solar and wood heat, use of nonrenewable fuels could nearly be eliminated with currently available technologies.

To assure best use of the heat generated by this system, insulation levels in the Cunniff home were increased. All windows were triple-glazed, ceiling insulation was upgraded to R-38, and walls were insulated to R-11. Also, 80 percent of the home's windows are on the south side, which promotes passive solar heating.

In this system, three heating sources—a natural gas furnace, a wood-burning stove and solar collectors—are integrated with rock storage by an extensive duct system. The conventional natural gas forced-air furnace blows heated air through the ductwork. The stove contains an integral heat exchanger that transfers heat to a duct and then into the gravel-filled storage bin. The storage bin, filled with 1½-inch washed river gravel, has insulated wooden walls and is connected by ducting to the main duct trunk.

The solar collectors were built into a separate structure 6 feet from the southeast corner of the house. To meet local building code requirements, the collectors had to be oriented 20 degrees to the east of true south. Four concrete walls, set partially into the ground and topped with insulated wooden walls, form the base of the collectors. A door at one end of the structure allows access for system maintenance.

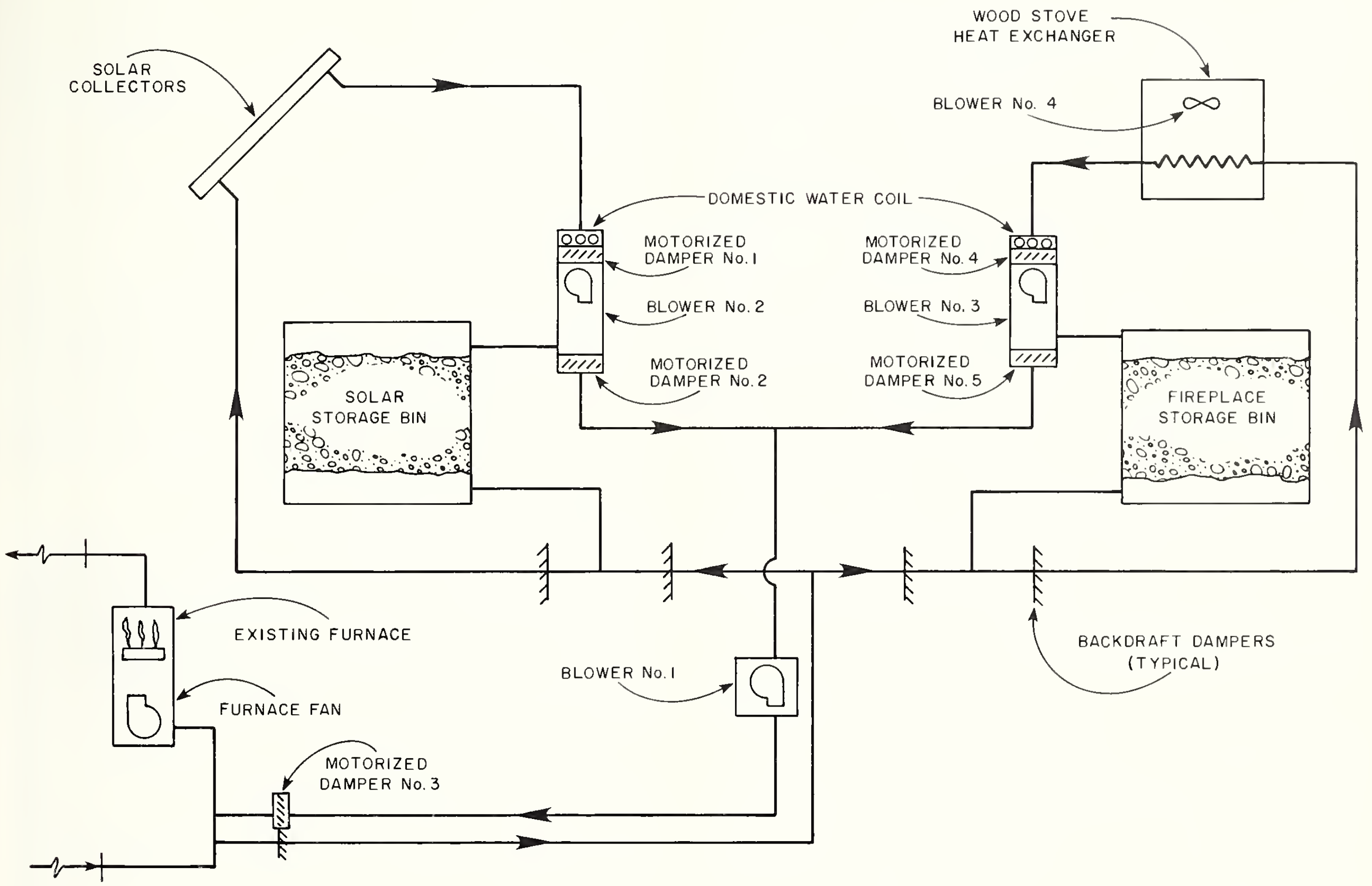
The flatplate air collector panels, which were mounted in two rows of 10 panels each, form a total solar collection area of 420 square feet. The entire array of panels is tilted at a 60-degree angle. The absorber plates are copper sheets coated with a copper-oxide selective surface. Each panel is framed with aluminum and covered with an inner layer of tempered glass and an outer layer of nonglare glass. The collector panels are joined by a single manifold to eliminate the need for additional ductwork to move the heated air through the solar cycle.

Air heated in the collectors is blown into a storage bin behind them. A differential controller monitors the temperature of the collectors and the storage bin to start the circulation of air through the solar heating cycle. A series of motorized dampers directs the solar-heated air either into storage or directly into the house via an insulated underground duct.

Cunniff installed separate heat-storage bins for the wood- and solar-heating units. Each bin is filled with 1½-inch washed river gravel. A ratio of 50 pounds of rock per square foot of collector area was used to determine the amount of gravel needed. Eight-inch lintel blocks were laid on the bottom of the bin to facilitate air circulation. The bin walls are concrete, insulated with 4 inches of rigid insulation and lined with ½-inch plywood. The walls were further insulated by packing earthfill against the building's outer north wall. The lid on the storage bin forms an airtight seal.

The two separate storage bins ensure that the system operates at top efficiency. To operate efficiently, the solar storage bin must be kept above a minimum temperature but below the collector temperature. If fireplace heat were stored in the solar bin, the storage temperature would rise to a point where solar collector efficiency would decline. Thus, the separate tanks allow solar heat to be used as much as possible.

In operation, the system is designed to use available solar heat first. If the heat drawn from solar storage does not meet demand, then heat from the wood stove storage bin will be used to supplement it. Only when these two sources do not meet the thermostatically set demand for heat will the gas furnace begin to operate. Cooled air from the house is returned by a separate duct to wood heat storage or to solar storage, or both.



PROBLEMS AND MODIFICATIONS

The Cunniff system was carefully planned. Schematic drawings were prepared to show the wiring required for the relatively complex automatic control system. A detailed computer analysis was run by engineers to determine the best size for the solar storage area. An oversized storage bin will not reach a usable temperature, wasting any solar heat collected, while an undersized bin wastes solar heating potential because it cannot store all the solar heat collected.

Acquisition of materials and equipment for the project was fairly easy. However, the solar collectors were not shipped on time, which caused some delay. Fans, motorized dampers, and controls were purchased from Solaron Corporation as a package for solar applications. A domestic hot water preheating coil, also made by Solaron, was added to the system but was not part of this grant project. Building materials were available locally.

Construction required more time than Cunniff anticipated. The contractor first installed concrete aggregate for the storage rock, but it was too dirty and had to be replaced with washed gravel. Installing the underground metal ductwork from the collector building to the house took about ten weeks.

The original plans were modified only slightly. Plans had been to use a home-built heat exchanger between the fireplace and the ductwork. A commercial wood stove with an integral heat exchanger was used instead, because the intent of the project was to demonstrate that available technology could be applied to an alternative-fuel heating system.

After the first winter of operation, Cunniff modified the heating mode of the system. Instead of allowing solar and wood heat to fill the storage bins first, he reset the controls to bypass storage and heat the home directly. Now, after the house is warmed to the desired level, heat generated by the collector or the stove is sent to storage. This change was made because heating demands in winter rapidly exhausted the stored heat. When sunlight was inconsistent and outside temperatures were extremely low, it took too long to replace the stored heat in the rocks. With the new arrangement, the alternative-heating sources can be used directly to maintain a comfortable temperature in the home. The gas furnace still operates only when the solar and wood heat sources cannot meet demand.

MATERIAL AND INSTALLATION COSTS

The following list summarizes 1978 costs of materials for the Cunniff project. Labor expenses are not included; about 200 hours of labor were donated by the grantee and his friends.

Solar System:	
1) Support structure	$ 6,483
2) Storage bin	840
3) Solar collectors	4,985
4) Ductwork	4,665
5) Fans and dampers	1,865
6) Controls	240
TOTAL	$19,078

Wood System:	
1) Storage bin	$ 420
2) Heat exchanger	750
3) Ductwork	3,160
4) Fans and dampers	1,110
5) Controls	240
TOTAL	$5,680

SYSTEM PERFORMANCE AND ECONOMICS

The combination of solar and wood heating sources has met or exceeded the planned performance levels for the Cunniff system. The two alternative energy sources supply approximately 85 to 90 percent of the home's annual heating load.

The solar system has performed well despite its orientation 20 degrees east of true south. Cunniff suspects that this orientation may cause the collector fan to begin running about half an hour earlier in the morning than it would if the collector faced due south. The early start causes relatively cool air to enter the system, thereby reducing overall performance. Afternoons are often cloudy; thus the southeastern orientation may make the most of the sunniest part of the day.

Helena

James Taylor

In November 1976, James Taylor of Helena received a Renewable Energy Program grant of $12,750 to construct a complex heating and cooling system for a new home with 1,912 square feet of living space. The system integrated an active air system with a fireplace, a wood stove, and a heat pump. Extensive duct work tied the different heat sources to a central storage room. Fans used with the heat pump provide space heating or cooling. A second solar collection system was built to preheat domestic hot water. For information or to view the project, contact Taylor at 8422 Green Meadow Dr., Helena, MT 59601; telephone 458-5232.

SYSTEM COMPONENTS AND OPERATION

Taylor's unique solar heating and cooling system was added to the commercial plans for his precut home by modifying the number and size of some rooms. The home was designed to conserve energy without sacrificing window area or room size. Walls were insulated with foam to a value of R-33; the ceiling was insulated with fiberglass batts to R-45. Double-glazed doors and windows were installed, and a crawlspace was built under the living area to contain the heating supply duct.

The three main components of this space-heating system are the solar collector, the heat pump, and a rock heat-storage room. When the solar collectors are not operating, a specially designed fireplace supplies heated air directly to the living area as well as to the main circulation system. A wood stove can heat the storage room directly.

Taylor chose an air collection system over a liquid collection system for several reasons. First, he believed that solar air heating could be more easily adapted to a forced-air heating system. Second, air-to-air heat pumps are more readily available. Third, air collectors are generally less expensive to construct and less difficult to maintain than liquid collectors.

The space-heating solar collector panels were built into a dormer-like structure on the south-facing roof of the home. The collector consists of a 2-foot framed space covered on the front by a double layer of Kalwall fiberglass. Kalwall was chosen because it is light, resists damage from expansion stress, hail, and rocks, and is less expensive than glass. Although fiberglass also is desirable because it does not create the reflective glare of glass, it is less attractive, has a shorter usable life, and transmits slightly less light than glass.

The collector is divided into wood-framed panels, each 4 feet wide. The panels are mounted vertically on 2-by-4-inch studs. Rear and side studwalls were insulated with 5 inches of foam insulation. The insides of the walls were covered with ½-inch exterior sheeting painted with a mixture of black exterior stain and lampblack. The collector panels were mounted vertically to eliminate the need for a sloping support structure. Efficiency losses associated with vertical mounting were partly recovered by placing a highly reflective coating on that section of the roof immediately in front of the collector.

In operation, heated air is drawn from the top of the collector with a 9-inch, ⅓-horsepower blower. An insulated duct carries the heated air to the 8-by-8-by-10-foot rock storage room on the main floor of the home. The walls of the storage room were framed with 2-by-4-inch studs and insulated with 5½ inches of continuous foamboard. Inside walls are covered by exterior plywood sheeting.

Two-thirds of the area of the storage room was filled with river rock and 1½-inch washed gravel. To ensure uniform air distribution, a plenum was constructed by placing cinder blocks along the floor of the room. These blocks were covered with rounded river rock to a depth of 5 feet. Steel straps connected to the storage room walls at 2-foot intervals keep the walls from collapsing under the pressure of the rocks. The rest of the space between the rocks and the ceiling acts as a plenum for distributing air from many sources. With around 20

tons of rock, the heat-storage capacity of the room is about 8,000 Btu/ °F.

A 3-ton Westinghouse HiReLi® heat pump represents the primary element of the heating system. The heat pump serves both as an integral part of the solar-heating system and as a supplemental heating source. Unlike conventional heat pump installations, in this project both the indoor and the outdoor units of the heat pump are located inside the rock storage room. One objective of the project was to create conditions in the storage room that would be superior to outdoor conditions and, thus, make the heat pump operate more efficiently in either a heating or cooling mode.

Solar heat, or heat produced by the wood stove or fireplace, is used to raise and maintain the temperature in storage. Also, the indoor half of the pump contains an electric heater that can be used when more heat is needed. For cooling, cool night air is pumped into the storage room. The pump then can efficiently extract cool air when it is needed most—during the heat of the day.

Because this system integrates many sources for heating and cooling, several modes of operation are possible, depending on the external temperatures at a given time. These modes are controlled automatically with a complex array of electric switches, motorized dampers, and thermostats. In general, these components are operated by logic circuits composed of remote bulb or thermostat sensors, low-voltage relays, and contractors. A standard differential thermostat controls the operation of the solar collectors. The heat pump employs a conventional thermostat modified to meet the unique operations of the system. A seasonal adjustment of the main control switch allows the system to be switched from the heating to the cooling function.

The following modes of operation are possible with this system:

1) **Heating directly from heat storage** - When heat is required and the storage temperature is high enough, dampers are opened or closed where necessary to allow heat to circulate from the storage room. Air is drawn from storage by the supply fan in the indoor unit of the heat pump.

2) **Heating with the heat pump** - In this mode, the warm air ducts at the top of the storage bin are closed and the pump draws heat from the warm storage air.

3) **Heating with auxiliary electric heaters** - If the above modes do not meet the heating demand, a second stage thermostat activates the electric heaters in the heat pump until the demand is met. Also, supplemental heat can be supplied indirectly by the wood stove adjacent to the storage room and by the fireplace linked with the supply and return air ducts.

4) **Cooling directly from storage** - Direct cooling can be attained by blowing cool air in storage (below 65 °F) through the duct system to the living space.

5) **Cooling with the heat pump** - When storage temperatures exceed 65 °F, the heat pump can function as an air conditioner by removing heat from the inside of the house and exhausting it into the rock storage room.

6) **Passive solar ventilation** - An open damper connects the roof collector to the home's return air duct. Heat in the collector causes air to rise through a vent in the collector, drawing cool air into the house through open northside windows.

PROBLEMS AND MODIFICATIONS

A number of problems arose during construction of this system. Taylor believes that most of the minor difficulties could have been avoided if more care had been taken in designing and drawing plans.

One problem involved the fan used to circulate the solar-heated air. The original ¼-horsepower motor on the fan encountered too much starting resistance at subzero temperatures. Such resistance caused the motor to burn out twice before it was replaced by a ⅓-horsepower motor. Also, Taylor found that locating the return air duct in the attic caused the duct to lose heat. He plans to move the return air duct to the crawlspace.

Other problems and modifications were associated with the rock storage system. Because commercial equipment is not designed to sort 3-to-4-inch round river rock, an attempt was made to sort the rock by hand. This task proved hopelessly tedious; thus, smaller 1½-inch washed gravel was used for about 75 percent of

the storage volume. In addition, locating the storage room above ground made it difficult to install the rocks. The above-ground location also complicated the placement of several duct runs. Underground storage would have simplified the construction, while making more floor area available for living space. The many inlets and outlets to the storage room, required by the complex control system, further complicated the construction and operation of the system; at each entrance, either a motorized or backdraft damper had to be installed to prevent airflow from bypassing the rocks.

MATERIAL AND INSTALLATION COSTS

The following list summarizes the material and labor costs of system components, at 1977 prices:

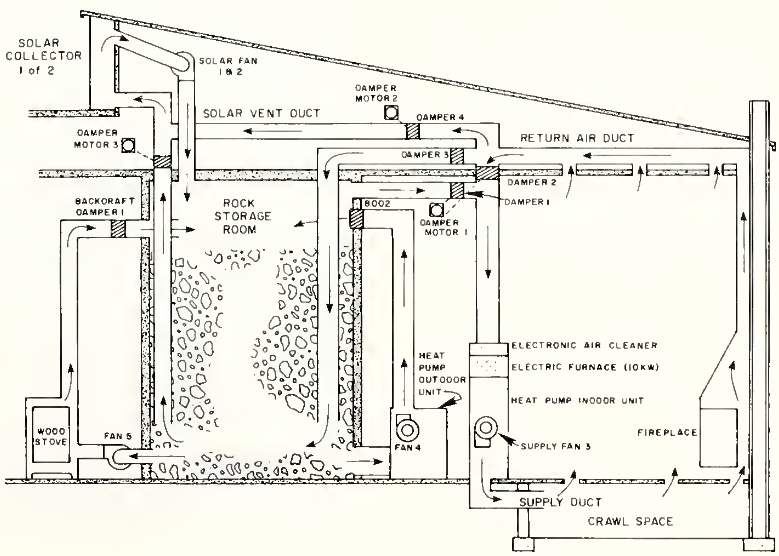
1) Solar collectors		
Materials	$ 1,962	
Labor	479	
		$ 2,441
2) Heating system		
Materials	$ 4,593	
Labor	1,517	
		$ 6,110
3) Domestic hot water system		
Materials	$ 664	
Labor	246	
		$ 910
4) Rock storage		
Materials	$ 753	
Labor	372	
		$ 1,125
5) Fireplace modifications		
Materials	$ 228	
Labor	132	
		$ 360
6) Electrical		
Materials	$ 185	
Labor	123	
		$ 308
7) Control and monitoring		
Materials	$ 714	
Labor	381	
		$ 1,095
8) Administrative		$ 434
TOTAL		$12,783

Labor costs include time spent in design as well as construction.

SYSTEM PERFORMANCE AND ECONOMICS

Due to minor problems and modifications, Taylor's system has not met its anticipated 33 percent solar fraction. However, the home also incorporates other heating sources—a wood stove, a high-efficiency fireplace, and a solar greenhouse.

Even if a solar fraction of 33 percent were obtained in the Taylor house, a short payback period would be unlikely. Nevertheless, by preheating water in a copper grid attached to a black-painted concrete wall, by using an efficient heat pump as the backup heating source, and by heating mainly with wood, Taylor has kept his monthly heating bills at an annual average of $33 per month. His highest utility bill has been around $60 for one month. Most of the home's space heat is supplied by about 6 cords of wood annually. Taylor believes that costs of a similar system could be lowered by about $2,000 if the experience and techniques learned through this project were used.



Bozeman

David Leavengood

David Leavengood was granted $10,500 from the Renewable Energy Program in November 1976 to demonstrate a home space-heating system that uses solar preheated air to increase the efficiency of an air-to-air heat pump. The heat pump, which incorporates backup electric resistance coils, was expected to replace the home's existing propane gas furnace and, in conjunction with the solar-heating system, significantly reduce the cost of space heating.

This home is located near Bozeman in Bridger Canyon. Persons who wish to view the system or obtain information from the grantee should contact Leavengood at 4276 Jackson Creek Rd., Bozeman, MT 59715; telephone 586-5717.

SYSTEM COMPONENTS AND OPERATION

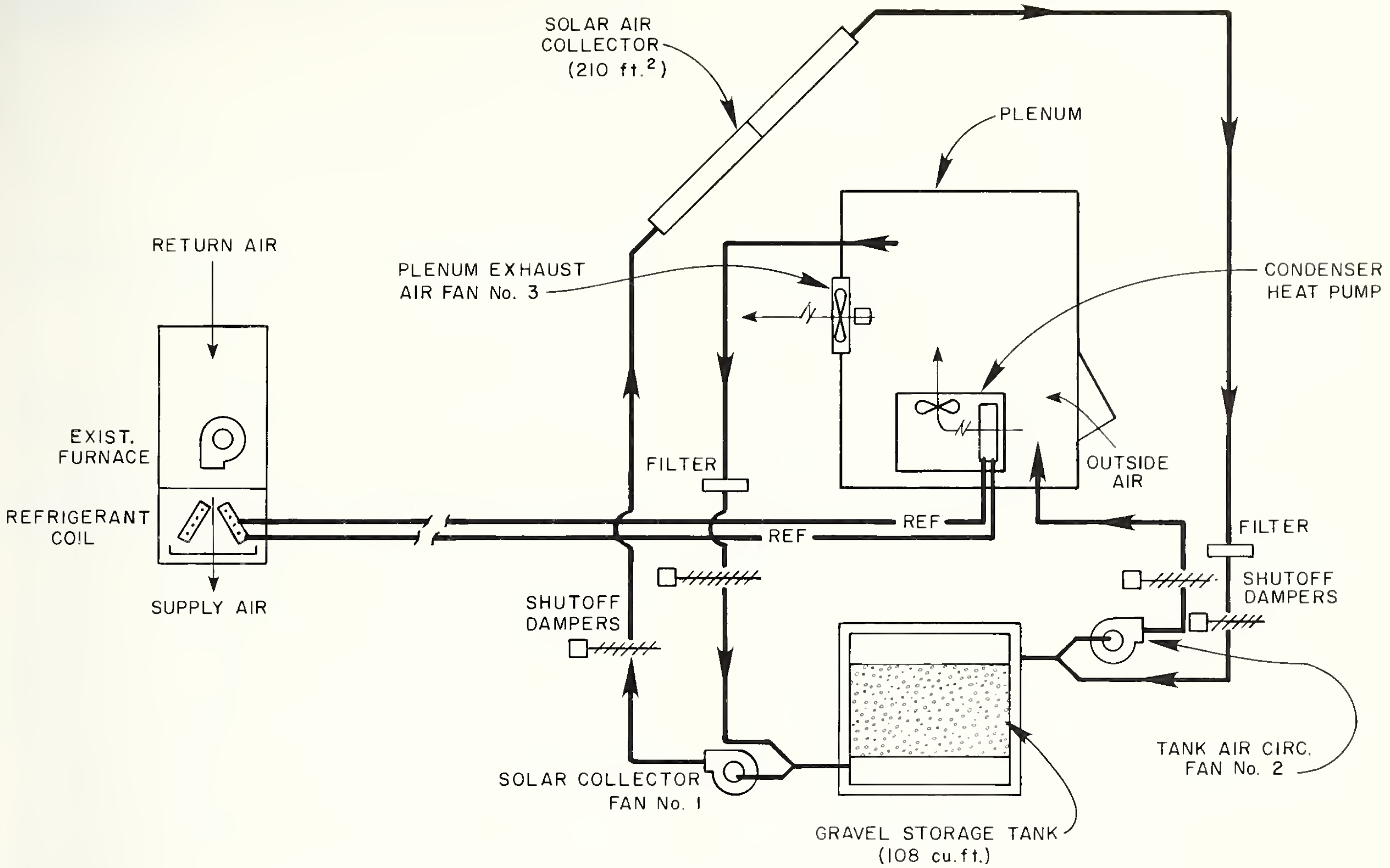
The flatplate air collector for this system is mounted at a 60-degree angle on a structure set away from the home. The wooden, shed-like collector building, 6 feet wide and 10 feet long, is insulated with rigid foam and rests on a concrete foundation extending from an underground concrete rock storage bin.

Ten Sunworks® flatplate collector panels with 210 square feet of surface area were mounted on the slanted, south side of the collector shed. The Sunworks® collectors were chosen for their high durability and efficiency. Each panel contains a copper absorber plate coated with a copper-oxide selective surface. The panels, framed in aluminum and double-glazed with an inner layer of tempered glass and an outer layer of nonglare glass, are joined at the top and bottom by one manifold to eliminate the need for separate ducting at each panel.

A collector fan in the shed blows air through the collector from the bottom to the top of each panel. The warm air is ducted down into the rock storage bin, which is insulated with rigid foam. An airflow plenum was built along one side and across the bottom of the bin with concrete blocks. The storage area measures 7 by 6 by 6 feet and contains about 9.3 cubic yards of gravel.

A second circulating fan draws warm air from an 8-inch plenum space between the top of the bin and the floor of the collector building. This air is ducted up into a metal plenum box on the floor of the shed. A 25-kilowatt Carrier® heat pump condensor unit was installed inside the plenum. A fan in the condensor unit moves air through a return duct to the storage bin for reheating. A small exhaust fan in the side of the plenum removes excess warm air to prevent overheating.

Two refrigeration lines coated with Armaflex® insulation were laid underground between the condensor unit and the heat coil unit inside the house. The heat pump warms the home by extracting heat from the air around the condensor unit. When the surrounding air temperature is between 35° and 50°F, the pump operates at peak efficiency. However, when the outside air temperature falls well below 32°F, the pump produces heat less efficiently. Leavengood's system was designed to boost and maintain top heat pump efficiency by solar heating the air in the condensor plenum.



Heat extracted by the heat pump is circulated throughout the house by the home's existing furnace fan and distribution ductwork. A thermostat controls operation of the heat pump. A Rho Sigma® differential control with temperature sensors operates the two collector fans and the two motorized dampers that regulate the solar collector heat cycle inside the collector building.

PROBLEMS AND MODIFICATIONS

Except for installing the collectors, all the work on this project was performed by building contractors. No major construction problems developed, and the entire project was completed with approximately 280 hours of labor. Construction was slowed by a 13-month delay in the arrival of the collector panels.

MATERIAL AND INSTALLATION COSTS

Following is a summary of the 1977-78 costs of materials and labor for this system.

Design	$ 1,300
Collector building with rock storage	4,000
Heat pump with installation	5,741
Sunworks® solar panels with installation	2,132
Collector flashing, connection of motorized dampers and fans	1,510
Electric controls	523
TOTAL	$15,206

SYSTEM PERFORMANCE AND ECONOMICS

The Leavengood project was monitored by an engineer under a Renewable Energy Program grant. The final monitoring report is available to the public through DNRC's Energy Division. Preliminary data indicate that during the monitoring period, which had to be conducted soon after the system began to operate due to delays in completing the project, as much as 50 percent of the site's solar heating potential was being lost because large fir trees shaded the collectors. Performance calculations were prepared for this system by the designing engineer. The system was expected to provide a solar heating fraction of 27 percent, while the collectors were expected to operate at an average annual efficiency rate of 32 percent. Additional performance data will have to be gathered before actual performance can be determined.

Leavengood remains convinced that integrating solar heating with another heating system, as demonstrated in this project, is a sound way to use solar heat in Montana. He doubts there is enough insolation to justify expensive, direct solar-heating systems. With this design, the collectors need only to raise air temperatures in storage to 35°F, a level of performance well within the year-round capability of solar collectors in Montana.

The calculated payback period for this system is 50 years, based on the assumption that it operates at peak performance levels. Leavengood expects the actual payback period to be longer, since he doubts that peak efficiency can be achieved at the site. He has noted a decline in the utility bill for the all-electric home and considers the system successful in reducing the home's consumption of commercially supplied power.

According to Leavengood, several approaches could be taken to reduce the cost of this system. Building the collector unit into the house could substantially reduce costs by eliminating the expensive collector building. Also, the collector may be larger than necessary to provide the relatively small amount of heat needed to boost the efficiency of the heat pump. During the summer, the temperature inside the collector building often rises above 120°F. This heat is presently vented out and wasted. Leavengood believes that investing about $600 in a water preheating tank may make better year-round use of the system and shorten the payback period. A production model of this system also could be developed at a lower cost by using prefabricated concrete septic tanks for the rock storage bin. This innovation could improve storage efficiency, as well as reduce the costs of materials and labor.

Bozeman

George Mattson

An $8,000 Renewable Energy Program grant was awarded to George Mattson in July 1977 to demonstrate a hybrid (passive and active) solar-heating system using readily available equipment and lumberyard materials. For more information or to arrange a visit, contact Mattson at 109 East Main, Bozeman, MT 59715; telephone 587-1240.

SYSTEM COMPONENTS AND OPERATION

Energy efficiency was emphasized in the design of the Mattson's 3,400-square-foot home. The house features compact living space with an open upstairs loft. The home faces southwest, with the air collectors mounted on the south wall. The walls are recessed approximately 2 feet into the ground to reduce exposed wall areas and to gain some insulation from the earth. An interior masonry wall stores heat and acts as a heat sink to balance daytime heating and nighttime cooling. To conserve heat, the bedroom and shop areas can be isolated from the rest of the living space. The home is well insulated with 12 inches of fiberglass in the ceiling and 6 inches of fiberglass in the walls.

The solar collector was expected to provide all of the home's space-heating needs down to -10°F. Solar heat gained passively through windows on the south wall was to supplement home heating. A centrally located wood stove and a forced-air gas furnace were to provide additional backup heat. Solar heated air enters the conventional heating system through a duct and is distributed by a fan in the gas furnace. A crawlspace was insulated at ground level to act as a warm air supply plenum.

The Mattsons' solar air collection system was designed and installed by Energy Alternatives, Inc. of Moscow, Idaho. The unit, a Model V-3® , was prefabricated and shipped to Bozeman. All automatic controls for the integrated system were provided by the company. A three-person installation team, assisted by two local glaziers, installed the collector in one week. All the ducts were built at the site in the back of a truck that contained a mobile sheet metal shop.

The collector, mounted at a 60-degree angle, has 600 square feet of surface area and is boxed in aluminum backed with Celatex® insulation to a value of R-18. The outer glazing is 1/8-inch tempered glass. An inner layer of Mylar® helps to prevent heat loss. A 5-inch space exists between the inner cover layer and the absorber. Accordion-pleated aluminum foil constitutes the absorption surface. The deep-V folds follow the vertical run of the collector and are designed to absorb heat through multiple reflection. Air flows on both sides of the absorber, creating a large heat-transfer area.

Cool air from the house or air from storage enters the collector from a bottom duct as warm air exits through a duct at the top. A vent at the top of the collector can be opened for summer cooling. A manual damper between the collector and the house opens to permit passive heating through the collector.

A sloping frame, constructed from 2-by-6-inch studs, extends down the south wall to the rock storage bin and supports the collector array. Because the storage bin is immediately below the collector, heat travels only a short distance in the solar collection circuit. The concrete block bin was constructed as part of the home's foundation. Side walls were insulated on the outside with 2-inch rigid foam. The bin's floor rests on the ground and is not insulated. A loose concrete-block duct system was extended from the floor up to the collector to allow air to flow through storage. A steel water tank was placed in the bin to absorb heat from the rocks and preheat domestic hot water.

Thirty cubic yards of unwashed 1½-inch gravel, used to store collected heat, was poured from a concrete-mixing truck into the bin. Aluminum foil covers the rock. To insulate the bin, the foil was covered with 2 inches of dirt. The bin then was sealed with a wooden lid insulated to R-30 with fiberglass batts.

A system of thermostats, motorized dampers, back-draft dampers, and a belt-driven, squirrel-cage fan

automatically operates the active heating system. Thermostats are set to use solar heat whenever possible. Warm air leaving the collector can be directed through the gas furnace to either the crawlspace distribution system or into storage. Cool return air can be ducted either through the collector or through the storage bin for heating. Heated storage air can be drawn for heating when solar collection stops. A wood stove contributes to heating through a heat recovery unit attached to the stove pipe. A separate fan in this unit blows heated air off the stack and into the ductwork for distribution to the living area.

The upstairs loft is heated by warm air rising from the ground floor and by heat stored in the passive storage wall. Much of the rising air gathers in a skylight above the loft. A ceiling fan inside the skylight pushes this air back down to the lower level.

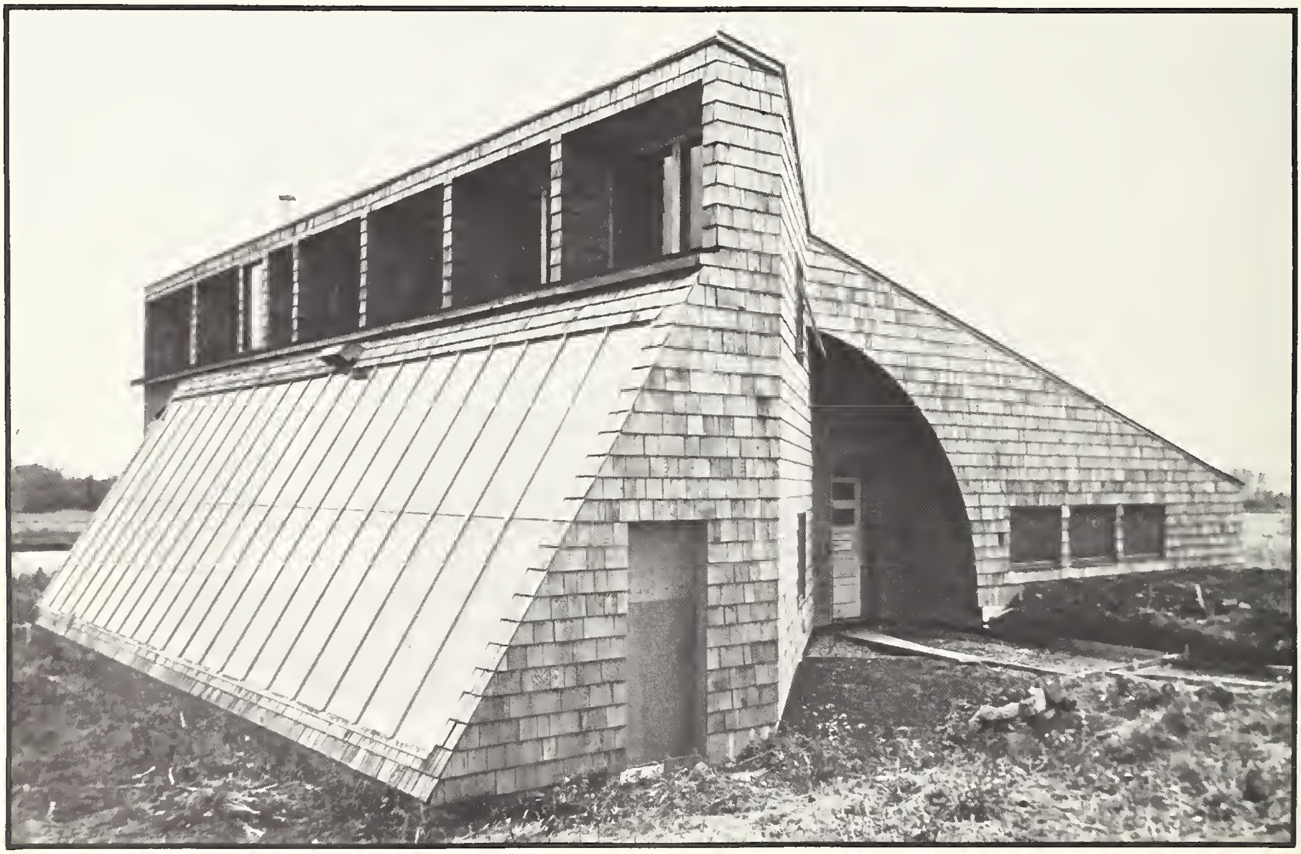
PROBLEMS AND MODIFICATIONS

After working with a system that involves rather elaborate ductwork and many operating modes, Mattson stresses the importance of careful engineering of the duct system and airflow patterns. Badly designed airflows and air leaks from ducts and dampers can dramatically affect system performance. Therefore, time and effort devoted to planning and design will be well spent.

Using the furnace fan as the collector circulation fan apparently caused the fan's motor to fail. Heated air from the solar loop passing over the fan is thought to have caused the failure. To solve this problem, a belt-driven fan was installed with the motor located outside the duct.

A potential problem with solar easement, the legal access to sunlight, also has developed. The collector apparently creates some glare, which a neighbor to the south found irritating. The neighbor has planted several pine trees along the property line. When mature, the trees undoubtedly will reduce the sunlight available to the collector.

Initial operation of the system revealed a "cycling" problem in which dampers would shift and the fan would begin drawing air from the collector. The fan would run for only 10 to 20 seconds before stopping for a short time and then starting up again. The problem was caused by the thermostatic sensors in the collector. The fan was activated when the sensors indicated that enough heat was present for heating, but the air passing through the collectors cooled the sensors to the shut-off point. Energy Alternatives, Inc. solved this problem by sealing the summer vent and installing a bypass switch for the differential heat sensors.



Some problems have been encountered in regulating the two speeds of the furnace fan. Although the fan was rewired to run at high speed only, both automatic and manual control of the fan has been difficult to maintain. Finally, although the slope of the collector keeps snow from building up on the cover, the snow piles up at the base and eventually covers the lower portion of the collector face. Mattson recommends elevating the collector about 3 feet off the ground rather than 18 inches.

MATERIAL AND INSTALLATION COSTS

Foundations and concrete block storage bin	$ 700
Concrete block storage ducts	74
Gravel (22 cubic yards	134
Preheat water tank	85
Collector floor	100
Collector framework and enclosure	150
Collectors, ductwork, glazing and controls	8,980
TOTAL	$10,223

SYSTEM PERFORMANCE AND ECONOMICS

Extensive monitoring of the Mattsons' heating system was conducted by a private engineer in the spring of 1979; the results are available from DNRC's Energy Division. During much of the monitoring period, the home was unoccupied. Malfunctions of the fan, dampers, and controls, as well as high heat losses that were partly reduced by installing a heat distribution ductwork, combined to make accurate operational monitoring impossible.

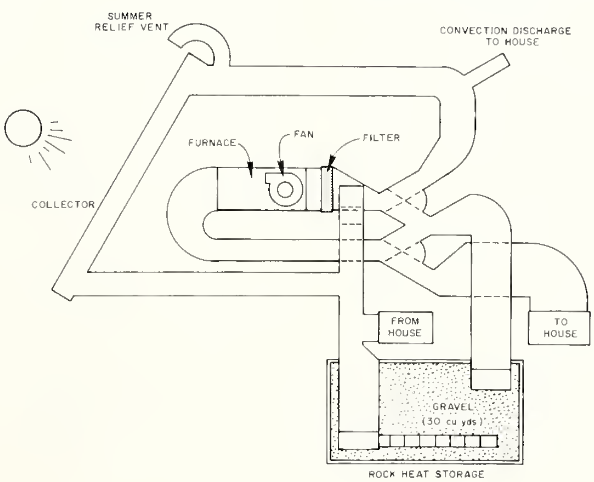
Unfortunately, some of the "bugs" in the system have persisted. As a result, it remains difficult to assess overall performance. However, evidence suggests that the system is not likely to achieve the high goals originally set for it. While 100 percent of the home's space-heating need was to be provided by solar energy, Mattson accepts an estimated annual solar fraction of about 40 percent.

Operation of the system has shown that little heat can be stored during winter months when solar availability is low and heat demand is high. Occasional direct daytime heating from the collector represents most of the solar contribution during these months. Solar storage is useful, according to Mattson, mainly in the spring and fall. He questions the economic justification of an investment in heat storage under these conditions.

Mattson's collectors can be operated passively because of their excellent air flow and heat absorption design. Depending on the amount of sunlight available in the passive mode, the collectors can produce inside temperatures 20° to 40°F above outside temperatures. Mattson contends that passive collectors should be considered for other solar uses because they often can contribute a significant amount of heat with even the simplest design.

As with other similar solar systems with relatively high initial investment costs, the Mattsons' solar air collection system is economically feasible only when compared to the costs for oil or electric heat. Natural gas, which is used along with wood to provide extra heat for the Mattson home, is currently priced low enough to be economically more viable than this solar-wood-gas hybrid system.

In a 12-month period from 1979 through the winter of 1980, the Mattsons' home consumed only $38 worth of natural gas. The rest of the home's space heat was provided with wood. Inside temperatures were kept relatively low; therefore, the total annual cost of heating fuel for this large family home was low.



Bozeman

James Orvis

A Renewable Energy Program grant of $3,700 was awarded to James Orvis in July 1977 to demonstrate the feasibility of retrofitting an active air solar system for space heating in a mobile home. Orvis believed that because mobile homes are increasingly popular in Montana, it would be especially worthwhile to demonstrate a workable, owner-built solar-heating system for these living units.

An active air system was chosen for this retrofit project for several reasons. First, materials for air systems were believed to be less expensive than those for liquid systems. Second, the problems of leaking and freezing associated with liquid systems are avoided with air systems, and air systems tend to be more durable because they do not use corrosive liquids as a transfer medium. Finally, air systems can be easier to design and build than liquid systems.

To visit or to obtain information on this project, contact Orvis at Route 1, Box 347, Bozeman, MT 59715; telephone 586-6839.

SYSTEM COMPONENTS AND OPERATION

The Orvis solar system, named "Sunspot 1"®, was added to a 17-by-54-foot mobile home manufactured by Magnolia. The home rests on a cement-block foundation with a partial basement and a crawlspace under the building. An additional room measuring 12-by-15 feet was added to the mobile home, and the entire structure covered with a conventional roof. In conjunction with these modifications, the amount of insulation in the home was increased substantially.

The solar collector, built onto the home, faces south and is tilted at a 70-degree angle. This angle was chosen to increase solar collection in the winter and reduce solar collection in the summer. The collector was framed with 2-by-4-inch studs and insulated with 3½ inches of fiberglass. Absorber plates were made from aluminum press plates primed and painted with flat black enamel. To gain heat, air circulates both in front of and behind the absorber plates. The collector, which has a surface area of 192 square feet, was covered with a single layer of Kalwall fiberglass. Fiberglass allows a large portion of the visible light spectrum to pass through to the absorber plate. Sunlight strikes the black aluminum surface and heats it directly. At the same time, heat waves are radiated in all directions. Because the fiberglass cover is coated with Tedlar®, a material that is opaque to infrared wavelengths, additional heat is trapped in the space between the fiberglass and the back of the collector. The heated air can be moved directly to the living space or into storage for later use.

The storage area is near the north end of the home in a crawlspace beneath the gas furnace. A horizontal storage design was chosen over a vertical bed because the crawlspace is small. The storage bin was constructed from wood and insulated with fiberglass batts. A plastic sheet was used as a vapor barrier and the walls were reinforced with wire mesh. Air flow baffles, made from particle board, were placed in the bin to channel heat from the top of the pebble bed, where the collector air enters, to the pebbles on the bottom. The bin was filled with 4 cubic yards of 1½-inch washed river gravel.

A Heliotrope® differential thermostat operates a four-speed squirrel-cage fan that circulates air through the collectors to storage or into the plenum of the gas furnace distribution duct. The thermostat senses the collector temperature and the storage bin temperature so that when the collector temperature drops to within 35 °F of the storage temperature, the blower stops, thus conserving heat in the storage bin. Heat stored in the pebbles can be drawn off by the furnace blower and ducted into the home.

Metal insulated ducting was constructed to carry warm air from the collector to storage. The duct runs across the top of the bin to an intersection where the warmed air flows either into storage or up into the furnace ductwork. When a motorized damper is open, the air flows up into the furnace for space heating. When the damper is closed, the air flows horizontally across

the storage bed where it can be stored in the bin or recirculated through the collector along with cool air returning from the furnace ductwork. When the collector fan is off and both dampers are open, heat from storage can be obtained by cycling air from storage through the furnace ducts and back to storage for reheating. Finally, with the dampers closed, the entire solar system can be cut off and the home heated with natural gas. A separate differential thermostat monitors the temperatures in the rooms and in storage to determine the operational mode of the furnace and dampers.

PROBLEMS AND MODIFICATIONS

Orvis found that most of the materials needed for this project were available in Bozeman. Ordered materials were shipped promptly and arrived without damage. The differential thermostats, however, created a noise problem; they were connected to a transformer that continually produced a loud, buzzing noise due to vibration. As a result, Orvis has reservations about using Heliotrope® thermostats and advises others of this possible problem.

Most of the work on the project was performed by unskilled laborers rather than by contracted builders with machinery. This lowered costs but slowed construction time. Construction and filling of the storage bin was particularly difficult and slow. Most of the work took place under the home in the small crawlspace. As with most existing structures, much of the home and crawlspace was no longer square or plumb. Thus, carpentry was difficult. Such a condition represents a major hurdle for any retrofit project. After the bin was filled with rock and sealed, some settling occurred. This settling created heat leakages that have undoubtedly lowered the system's performance.

Orvis discovered some critical design flaws in his system. First, heat exchange in the horizontal storage bin is not as efficient as it would be in a vertical bin. Although the baffles installed in the bin do promote air circulation across all the pebbles, warm air tends to flow through the upper part and cool air through the bottom. Such stratification impairs the bin's ability to gain heat. In addition, Orvis recommends building a concrete bin and locating the solar collector as close to the bin as possible to lessen heat loss. He also believes that his storage volume was too small to assure best use of collected solar heat.

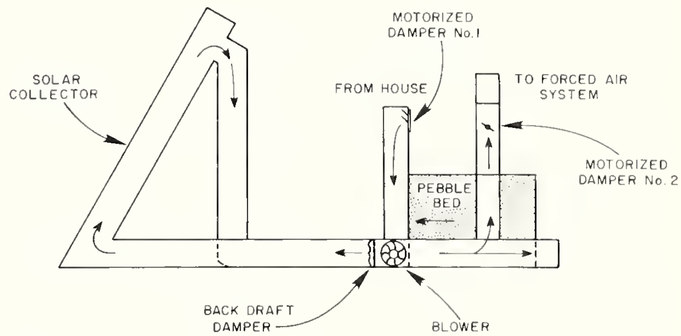
Using shop-made metal ducting is expensive. Orvis believes costs can be reduced without lowering performance by using less expensive ducting materials, fabricated on the site.

MATERIAL AND INSTALLATION COSTS

A summary of the material and installation costs of the Sunspot 1® system at 1977-78 prices follows:

1) Supplies	$4,464
2) Labor	844
TOTAL	$5,308

Labor represents between 750 and 1,000 hours of work.



SYSTEM PERFORMANCE AND ECONOMICS

The data available on this system indicate that collector performance has reached the expected level. The system heats 400 to 500 cubic feet of air per minute to 130°F. The performance of the heat-storage system has not been measured, but indications are that heat loss and the horizontal-flow design reduced system efficiency.

In 1978, the cost of natural gas for the Orvis home was about $300. Of this amount, about half was spent to heat water. Since the solar system was not used to heat water and because it supplied only a fraction of the home's total space-heating needs, its payback period will not be reasonable. Orvis concluded that while he learned a great deal about solar technology through this grant project, a retrofit solar air-heating system is feasible for mobile homes only where fuel costs are extremely high and alternatives such as wood heat are not available.

Bozeman

Charless Fowlkes

Charless Fowlkes of Fowlkes Engineering was awarded a Renewable Energy Program grant of $25,000 in July 1978 to design, construct, and monitor the performance of an integrated solar air, wood, and electric space-heating system in a mobile home.

Fowlkes believes that the completed home could serve as a prototype for eventual production. Integrating the solar-heating system into the mobile home at the factory was expected to reduce the cost of the system enough to make it a feasible renewable-energy housing alternative.

The final report on this project contains a computer analysis of the extensive performance monitoring conducted as a part of the grant project. Information from the report can be obtained from the Energy Division, DNRC, 32 South Ewing, Helena, MT 59620. For information from Fowlkes, contact him at Fowlkes Engineering, 31 Gardner Park Dr., Bozeman, MT 59715; telephone 587-3779.

SYSTEM COMPONENTS AND OPERATION

The mobile home fitted with Fowlkes' heating system was manufactured by Gallatin Homes Corporation in Belgrade. The walls and floor of the home, an energy conservation model, are insulated to a value of R-20. The ceiling is insulated to a value of R-38. All windows are double-glazed. Insulated skirting, placed around the bottom of the 14-by-56-foot home, supports the bases of the collectors and reduces heat loss. The Gallatin model was chosen because the design allowed much of the south wall to be retrofitted with an air collector.

Three separate collector banks are mounted vertically on the south wall of the home. A south-facing window and a door on this wall made placing one large collector on the wall impossible. Each collector panel is framed in aluminum. Behind each collector, 3½ inches of fiberglass insulation was attached to the wall of the home. Twelve-gauge steel channel spacers were bolted to the wall to support each collector absorber plate. The absorber plate consists of sections of 2½-inch corrugated steel, overlapping to fill the collector space. The collector is covered with two layers of glass with a low iron content, known commercially as Sunadex® . The sides of the collector banks contain neoprene spacer blocks faced with 1-inch fiberglass board insulation. Together, the three collector banks produce 340 square feet of solar-collecting surface area.

Air flows from delivery ducts in the wall of the mobile home and moves horizontally across the collector panel between the absorber plate and the wall. A small kitchen window was incorporated in the structure of one collector bank; a section was cut from the collector to accommodate this window. Translucent fiberglass was installed in the collector to allow light to reach the window.

A rock heat-storage bin was built into the ground beneath the home. The walls of the bin were extended approximately 12 inches above the ground so that, when the mobile home was positioned over the 128-cubic-foot storage bin, the bin and the existing heat duct system could be connected. The walls were reinforced with 4-by-4-inch redwood posts and placed on concrete footings so that the bin and the home could be aligned.

The bin walls were built with an inner layer of ½-inch drywall board and an outer layer of ½-inch exterior fiberboard. The sheets were positioned to cover the taped seams of both wall layers. Polystyrene bead-board insulation, 4 inches thick, was placed between the wall and the ground. A bin floor was constructed by tamping fill dirt level with the concrete footings. Sheets of 2-inch polystyrene were laid on the dirt and ½-inch drywall board was attached to the walls to form the inner floor. The entire excavation was lined with a polyethylene sheet to prevent moisture from seeping into the bin.

An airflow plenum was created on the bottom of the bin by laying bond beam block, with the openings parallel to the main flow of air, along the bin floor. The

blocks were placed 3 to 4 inches apart, with open ends up, against the wall of the storage box. A layer of steel lath was placed over the blocks to keep rock out of the airways. A warm air plenum was formed by leaving an empty space, 8 inches deep, at the top of the box between the storage rock and the lid.

Washed river rock, ¾ to 1½ inches in diameter, was placed in the box to absorb heat. The storage box lid was fabricated with an inner drywall layer and an outer layer of ¾-inch plywood built on a frame of 2-by-4-inch wooden studs. The top of the box was covered with a 12-inch fiberglass insulation batt to reduce heat loss. A 42-gallon steel water tank was embedded in the rock to preheat the home's hot water.

Before entering the rock storage bin, solar-heated air is ducted into a plenum room containing a wood stove. This closet-like enclosed room is 35½ inches wide and 7 feet, 5 inches high. Sheet rock was mounted on the existing walls and floor to protect the room from fire. A frame of channel steel and steel studs was set along the perimeter of the room to hold the fireproof inner walls. The interior of the plenum room then was lined in sheet metal. Fiberglass insulation was placed in the wall behind the stove to reduce heat loss into the house.

The plenum room is enclosed with two sheet-metal insulated panels screwed into the steel frame. The door of the wood stove is fitted into this wall so that the stove can be fueled without opening the plenum room. The Earth Stove®, a shielded, air-sealed model, draws air for combustion through a 7-inch flue pipe extending through the floor of the home. A manual flue damper can be closed to prevent heat loss through the stove when it is not in use.

The stove plenum is the central heat distribution point for the system's eight distinct modes of operation. An electric resistance furnace next to the plenum adds auxiliary heat when necessary. The system, integrated with insulated metal ductwork, was automated by installing a differential thermostat to control the solar collector fan and damper, a furnace thermostat to control the stove damper and collector fan, and a two-stage thermostat to control the house fan, damper, and auxiliary electric furnace. Status lights indicate which systems are operating.

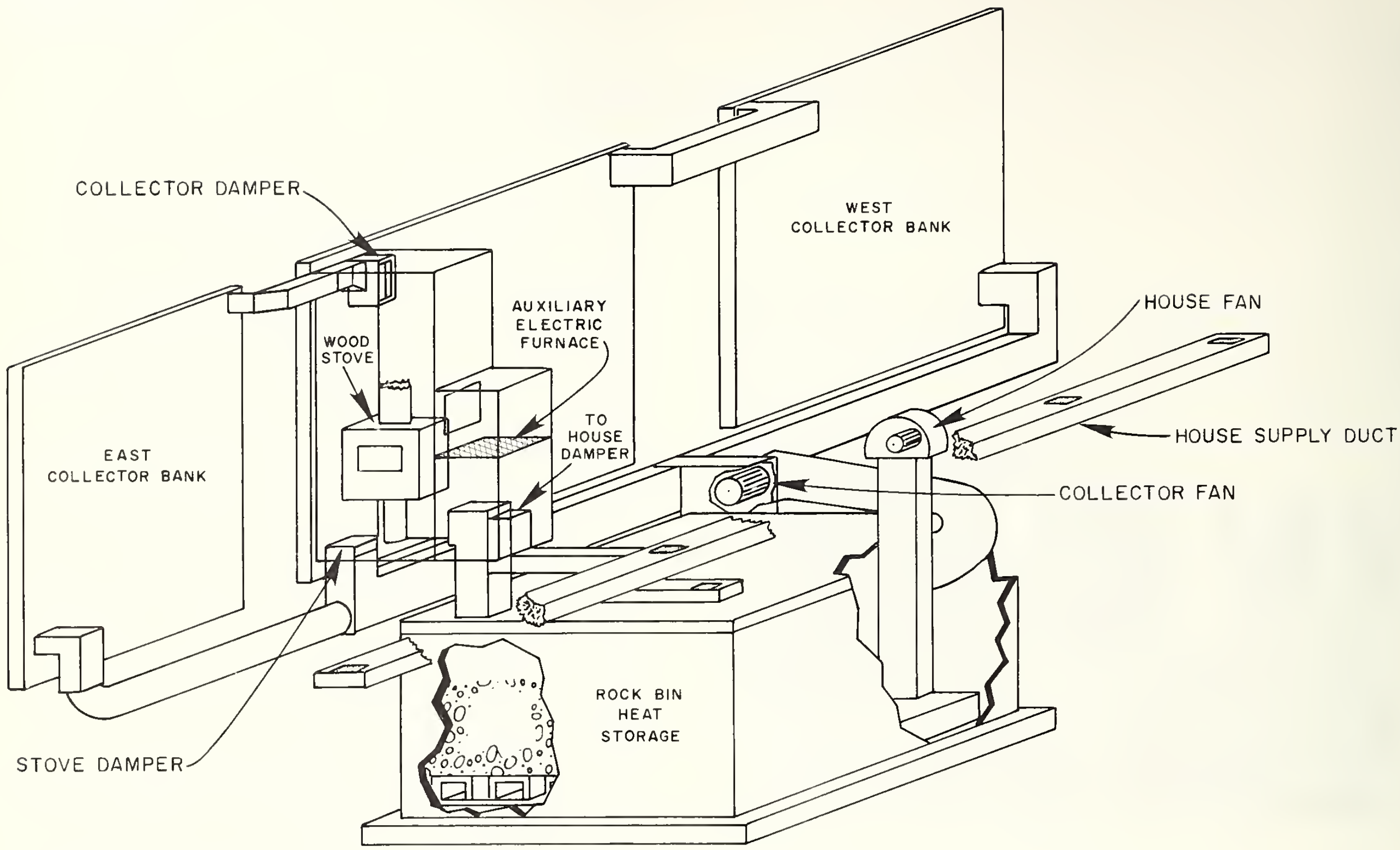
Without detailing all eight modes of operation, a general description of the airflow options seems instructive. Cool returning air enters at the bottom corners of the two collector panels mounted on either end of the home's south wall. The air rises and flows horizontally through insulated ducts to the middle collector panel. The air then enters the top of the plenum room where it can be blown directly down to storage, combined with wood stove heat for heating the storage rocks, or sent through the furnace directly to the room registers. Stove heat alone can be sent to storage or drawn up into the plenum and blown through the electric furnace for additional heating. The thermostats are set to use stored solar or wood heat before drawing auxiliary electric heat.

PROBLEMS AND MODIFICATIONS

Two minor problems caused some delay in completing this project. First, completing the collector was delayed when the first two shipments of cover glass were smashed in transit to Bozeman. A third order was placed and the shipment arrived three weeks later. Second, the monitoring phase was delayed because it was difficult to process the monitoring data.

A problem with the collector circuit arose during the system's initial operation. The collector fan continued to circulate air for about an hour after the sun had set. Inspection revealed that the wall of the home directly behind the collector held enough heat to keep the differential control operating when the sun could no longer provide heat to the system. Thus, the fan continued to circulate unheated air from the collector into storage. As a result, when heat was needed shortly after sunset, cool air entered the living space before warmer air.

Original plans for this system called for sending electric heat produced during off-peak hours into storage. Fowlkes believed that this arrangement could demonstrate a way to ease the peak power demands expected to create serious power shortages in the future.



This off-peak heating was to be controlled by a timer connected to the electric furnace. Later monitoring indicated that because heat losses from storage were high, such a system would only waste energy.

A plan to preheat hot water in a tank contained in the storage bin also was dropped. Because temperatures under the home often were below freezing during the winter, the electricity needed to keep the pipes from freezing would reduce the economic incentive for preheating. Thus, the system was not connected.

After evaluating the monitoring results, Fowlkes recommended locating the heat storage and ductwork inside the heated living space. Although this would greatly reduce heat loss, it would also significantly reduce living area.

Fowlkes cited two other problems that suggest a need for further modifications. First, storing wood heat requires relatively careful operation scheduling if system performance is to justify the cost of the extra ductwork. The general public may not want to invest the time this system requires. Second, the fans used in the system were found to be noisy and distracting. Lower speed fans attached on flexible mounts could eliminate this problem.

Fowlkes recommends integrating vertical air collectors into the south wall, rather than merely mounting them on the wall. He also advises that collectors be designed to withstand temperatures of at least 250°F, that circulating fan motors should not be subjected directly to solar-heated air, and, finally, that collector glazings should be installed so that they can be removed if the home is moved.

MATERIAL AND INSTALLATION COSTS

The following list summarizes 1978 costs of materials and labor for the Fowlkes mobile home retrofit system.

1) Design	$ 2,912
2) Storage/pad system, materials and labor	1,235
3) Wood-heat system including labor	1,237
4) Electric furnace	370
5) Solar system including labor	5,455
6) Mobile home set up costs	1,134
TOTAL	$12,343

The cost of monitoring this system, $10,598, is not included.

SYSTEM PERFORMANCE AND ECONOMICS

The results of the system's monitoring were mixed. Collector efficiency was found to be slightly higher than calculated; the collector delivered 35 percent of the available solar radiation to the collector outlet on the days it operated. Unfortunately, however, high heat losses from storage made the entire system ineffective. In an average month, only 10 to 20 percent of the heat sent to the bin was returned for space heating. Also, although 30 percent of the heat generated by the wood stove was sent to storage, only about 4 percent was returned. Heat losses from storage thus reduced the wood heater's efficiency by about 25 percent.

Monitoring indicated that storage heat losses were due to air leaks rather than conduction. When the fan was activated, temperatures in the crawlspace would rise, confirming that air leaked from the bin. Despite the great effort spent to design and build a well-insulated bin, this effort seemed to be unsuccessful.

If the modifications proposed by Fowlkes were implemented, the performance and economic viability of this system could be dramatically improved. He estimated that the current solar heat fraction of 15 percent could be doubled, or tripled, if storage losses were eliminated. Improvements in the control system would further increase the solar fraction. Adding a workable hot water preheater also would augment the solar contribution, improving the payback outlook for the system.

Big Timber

John Alexander

John R. Alexander was granted $10,972 in January 1978 to build a heating system in his new home that would collect solar energy through an active air system. The system would incorporate a specially built, highly efficient wood furnace for backup heating. Two fireplaces, on different floors of the home, were added for additional room heating. The large, two-story house serves both as a home and office for Alexander. Much of the construction work was done by Alexander and Colin Jones, who prepared the plans and designed the heating system.

For information or to visit the home, contact Alexander at Box 426, McLeod Route, Big Timber, MT 59011; telephone 932-3345.

SYSTEM COMPONENTS AND OPERATION

Heat conservation was a primary consideration in the design of the Alexander home. The roof and solar collector were insulated with 3¼-inch Fesco® foam and 6 inches of fiberglass. The 2-by-6-inch framed walls were sprayed with a 1-inch layer of foam and covered by 4-inch fiberglass. All windows were double-glazed; special attention was given to sealing the windows adequately.

Insulation was placed between the foundation footings and the concrete floor slab to lessen heat loss to the earth. Also, a large daylight basement is partially sheltered by the earth surrounding it. The balance of the house was built as close to the ground as possible to reduce the heat loss to the area's strong winds. Passive solar collection was achieved by placing most of the windows on the south side of the home; north-side windows are few. All windows were fitted with interior insulated shutters or drapes.

An attic, built like a dormer on the peak of the roof, serves as the home's solar collector. This attic, which runs along the east-west axis of the home, faces south to increase solar exposure. To simplify construction and reduce visual impact, Alexander built his attic addition vertically on the roof. Performance limitations associated with the vertical mount were offset by covering the entire gently sloping south roof with old aluminum press plates. Calculations by Jones indicated that this reflective surface would increase heat collection enough to justify the design.

The attic roof slopes from the top of the glazing down to the north roof eave. The inside of the attic roof also is lined with reflective materials to capture an additional portion of the sun's low-angle winter radiation. In the summer, when the sun is at a higher angle, a roof overhang casts a shadow on the glazing, thereby reducing solar collection when little or no space heat is needed.

The entire attic functions as a solar collector. Solar radiation either falls directly on the attic floor or is bounced to the floor by the reflective ceiling. The interior of the collector was painted flat black. Aluminum sheets, hung from the ceiling and painted black, absorb the trapped heat. A powerful blower, taken from a swamp cooler, forces the warmed air from the top of the collector into a duct. Air drawn from the attic is replaced by cool air returned through the attic floor. This air rises as it is heated—to be drawn out again in the cycle.

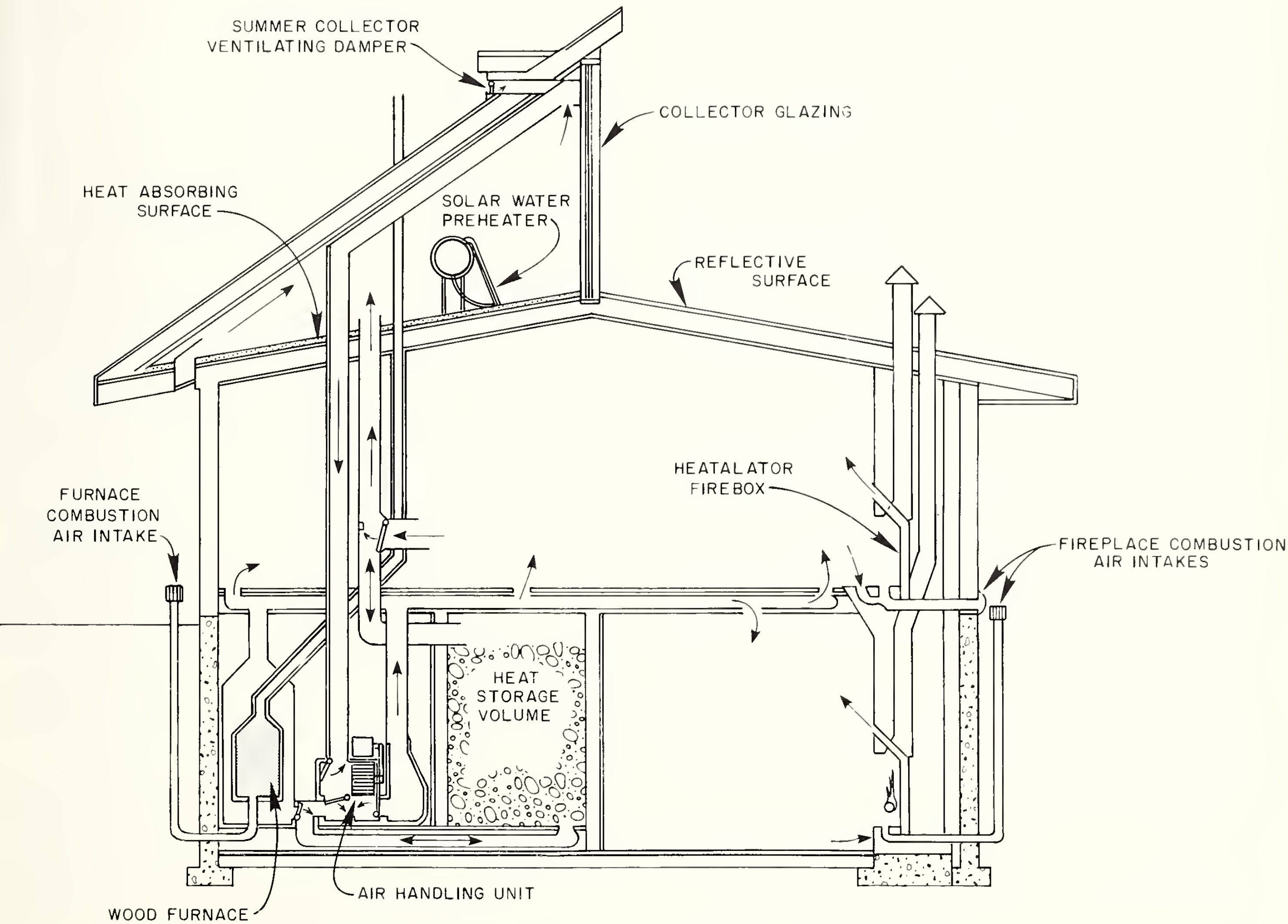
Solar-heated air flows from the roof collector down to the basement where heat is stored in a bin filled with 3-to-4-inch round rock. The bin was built in an "L" shape to fully use available space in the furnace room. The floor of the storage bin covers 62 feet. The walls, 5 feet, 4 inches high, were constructed from 8-inch concrete blocks with concrete-filled cores. The walls are supported by steel retaining grates inside the bin. The bin's 12-inch concrete slab floor is insulated with 2-inch rigid foam sheathed in plywood. A lid for the bin was made by insulating 2-by-6-inch joists with 6 inches of fiberglass and 1 inch of rigid foam. The lid was carefully sealed with a wooden sill and bolted to the bin walls.

The bin was designed to reduce heat loss through the top and bottom of the storage area while allowing some loss through the walls. Heat escaping from the walls helps to maintain the temperature of the adjoining living space. Heat in the basement was expected to help warm the second story of the home.

Alexander's solar-heating system is almost totally automatic. When a differential thermostat senses that collector temperatures are higher than storage temperatures by a set amount, dampers in the air-handling unit are automatically aligned to permit air to flow into the storage bin. At the same time, return dampers open to allow another fan to blow cool air up through the collector. Heating demands can be met by drawing air from the collector-storage loop into the main supply duct or, when there is not enough heat in the collector, from storage only.

A Hippert wood furnace, built in Whitehall, provides auxiliary heat. The furnace is designed to operate efficiently and is controlled by the system's electric control ducts. If the furnace is operating and producing more heat than needed, the air handler will automatically send the furnace heat into storage. Heat for the office section of the home is regulated by a separate thermostat that activates a damper to divert heated air from the supply duct into the office.

Domestic hot water is preheated by both the solar collector and the Hippert furnace. Water is piped up to the collector and flows through a serpentine pattern of copper pipes suspended in a rack on the floor of the collector. An 8-by-11-inch sheet of copper was soldered to each length of pipe to increase heat absorption. The entire array of pipes, rack and copper sheets was painted flat black. To enable the furnace to preheat water, an air-to-water heat exchanger was built into the furnace by the manufacturer.



PROBLEMS AND MODIFICATIONS

Installing the complex ductwork and constructing and filling the storage area were difficult and time consuming. The ductwork plans had to be altered to fit the structure, and wiring the controls to the fans and dampers required a lot of planning and work. Alexander estimated that about 40 working days were spent constructing and filling the storage area.

The method for preheating water in the collector had to be revised several times before a workable system was developed. At first, copper pipes were tacked in a serpentine pattern to the floor of the collector. However, the temperatures attained with this method were not high enough to prevent freezing during the winter. A second attempt to circulate water through an automobile radiator, painted black and positioned near the glazing, also failed due to freezing. In the final version, described above, Alexander obtained a large enough heat-absorption area to protect the pipes from freezing.

Only minor changes were made in the original plans for this system. The reflective ceiling inside the collector, installed to capture additional solar energy, actually reduced system performance; the angle of the ceiling reflected light back through the glazing rather than onto the absorption surface. This problem was corrected by hanging black aluminum sheets from the ceiling. Alexander believes that triple glazing should have been used to limit heat loss from the collector and that the heat-absorbing back of the collector should have been closer to the glazing. The large area inside the collector simplified construction and maintenance but probably reduced performance; it is too large to heat rapidly, and, thus, increases heat loss potential.

Rather than depending on one large fan to circulate air through the entire storage cycle, Alexander installed three small fans. Although one fan probably would have been adequate to move a sufficient volume of air, Alexander believed that the three fans, strategically positioned, would provide the best air-handling efficiency.

Alexander believes that too much effort may have been devoted to developing an automatic control system. One motorized damper failed soon after installation. Also, automatic regulation of the Hippert furnace has not been effective. To obtain top performance and better control of the system, Alexander believes a central temperature panel with manual switches should be used.

MATERIAL AND INSTALLATION COSTS

1.	Solar collector (attic) (including water preheater)	
	Materials	$ 9,286
	Labor	675
2.	Heat storage	
	Materials	795
	Labor	349
3.	Air-handling system	
	Materials	2,142
	Labor	80
4.	Wood furnace (installed)	955
5.	Insulated drapes	640
6.	Plans and administration	564
	TOTAL	$15,486

Most of the labor for this project was donated by Alexander. Labor figures presented here are for contracted services.

SYSTEM PERFORMANCE AND ECONOMICS

Through its initial operating period, the system performed as well as expected. The vertical collector and roof reflectors generate heat well; temperatures in the attic during the best solar collection days have approached 150°F. However, Alexander believes that a triangular glass front might capture more early morning and evening heat, while still gathering heat at midday. He also believes that blowing cool return air up and warm air down into the solar cycle is not very efficient; the system does not take advantage of the natural tendency for warm air to rise.

Alexander estimates that the average annual space heating costs for a comparable home in the Big Timber area would be about $700. He expects the solar system alone to provide about half the home's heat load per year. Thus, heating his home should cost about half this amount. An estimated annual savings of $300 per year for water heating also is anticipated. With current utility rates, the payback period for this system should be about 26 years.

Glendive

Michael Stoltz

In November 1976, a Renewable Energy Program grant of $3,805 was awarded to Michael Stoltz of Glendive to demonstrate a simple, owner-built solar air space-heating system. A special objective of the project was to demonstrate construction techniques for inexpensive, efficient solar collectors capable of performing at or above the standards of more expensive commercial units.

Although Stoltz no longer lives in Glendive, information about his project can be obtained by writing to him at 2835 Wingate, Eugene, OR 97401.

SYSTEM COMPONENTS AND OPERATION

The Stoltz's two-story, split-level solar home was built on a south-sloping lot in the Hillcrest addition of Glendive. The site was considered ideal for many reasons. The slope allowed the collectors to be constructed at ground level for easy maintenance and installation. Also, solar access was unobstructed by buildings or trees, and the location of the home on the south slope allowed Stoltz to incorporate passive solar features such as large south-facing windows.

The solar collector was the primary component of this system. The collector consists of a bank of ten 4-by-16-foot panels, one of which was designed to preheat domestic water. (The preheating system was not part of the project funded by the grant.) The nine other panels served as solar air collectors. Eight of these collectors employed beer cans as heat absorbers, the ninth incorporated a sheet of corrugated steel roofing to absorb heat.

The eight beer-can-type collector panels are backed with pressure-tested, waterproof plywood. A 3/8-inch sheet of plywood was attached to the middle of the box to form the absorber surface. The back of the absorber was insulated with a 6-inch fiberglass batt and faced with foil, which reflects sunlight back toward the collector cover.

Aluminum beer cans were cut horizontally to form small cups with one end open and the other closed. To determine the best height for the absorber cups, Stoltz built four collectors with cups 2 inches deep and four collectors with cups 2 5/8 inches deep. The difference in depth determined the distance between the cover and the top of the cups, a factor that Stoltz believed would affect air flow turbulance and collector performance. The distance between the cover and the absorber, depending on which cups were used, ranged from ¾ of an inch to 1½ inches. The cut cans were mounted on aluminum press plates and screwed to the plywood. The entire array then was painted black.

The panels were covered with an inner layer of heavy-duty, clear vinyl and an outer layer of Kalwall Sun-Lite® fiberglass. A felt door seal was placed along the edge of the panels between the two layers. A metal drip cap was screwed through the glazings into the collector panel sides. The coverings were sealed with silicone between the drip cap and the Kalwall fiberglass, as well as between the glazing and the panel sides.

The corrugated-roofing collector was constructed in much the same way as the beer-can collectors. In this case, however, the absorber plate was formed from a sheet of corrugated steel roofing and a sheet of 3/8-inch plywood. The two sheets were spaced 1 inch apart. The space created between them was sealed at both ends. Three holes were cut in each end of the metal plate to allow air to flow between the absorber plate and the plywood.

The collector was mounted on a steep slope in front of the house. The panels were tilted at a 60-degree angle and attached to a concrete foundation, which consists of a 21-inch concrete footing supporting a 6-inch wall. The collector was secured to the wall with 3/8-inch hook bolts and angle iron.

Both the top and bottom of the collector panels were joined by insulated plywood ducts. A used 10-inch furnace blower and motor moves air through the collector.

With this design, cool air leaves the split-level basement through a duct and enters the bottom of the collector; the air then passes over the heat absorber surface. At the top of the collector, warmed air is drawn into an insulated fan box. The fan in the box then forces the air through another duct parallel to the cool air return duct. Both ducts run underground.

The warm air enters the gas furnace plenum, where it can be circulated to provide space heat or added to the air warmed by the furnace to supplement the heat load. A storage medium was not incorporated with the system, though Stoltz believed that storage could be added. Given the amount of heat absorbed by the collectors, storage probably would further decrease the home's furnace heating requirements.

The solar system operates through a simple automatic heat-sensing switch. The furnace starter switch was wired to the collector fan and placed inside the warm air manifold of the collector. When heat in the manifold reaches 105 °F, the fan is activated to begin solar heating. When the manifold temperature drops to 90 °F, the fan stops.

PROBLEMS AND MODIFICATIONS

Stoltz encountered only two installation problems. Constructing the beer-can collectors was impeded because the cans were difficult to cut. After operating the collector, Stoltz was convinced that the steel roofing collector performed at least as well, if not better, than the beer-can model.

The second problem involved designing and building the collector ductwork. For the conventional metal ducts originally used, Stoltz substituted insulated ductboard, which made it easier to fit the ductworks to the system.

After several months of operation, the inner vinyl covering of the collector shriveled and tore under intense heat. The vinyl covering was removed and now only the outer fiberglass layer covers the collector.

MATERIAL AND INSTALLATION COSTS

The following list summarizes the material costs at 1978 prices for the Stoltz solar system. Labor costs are not included, nor are the costs of passive solar features and the coal furnace.

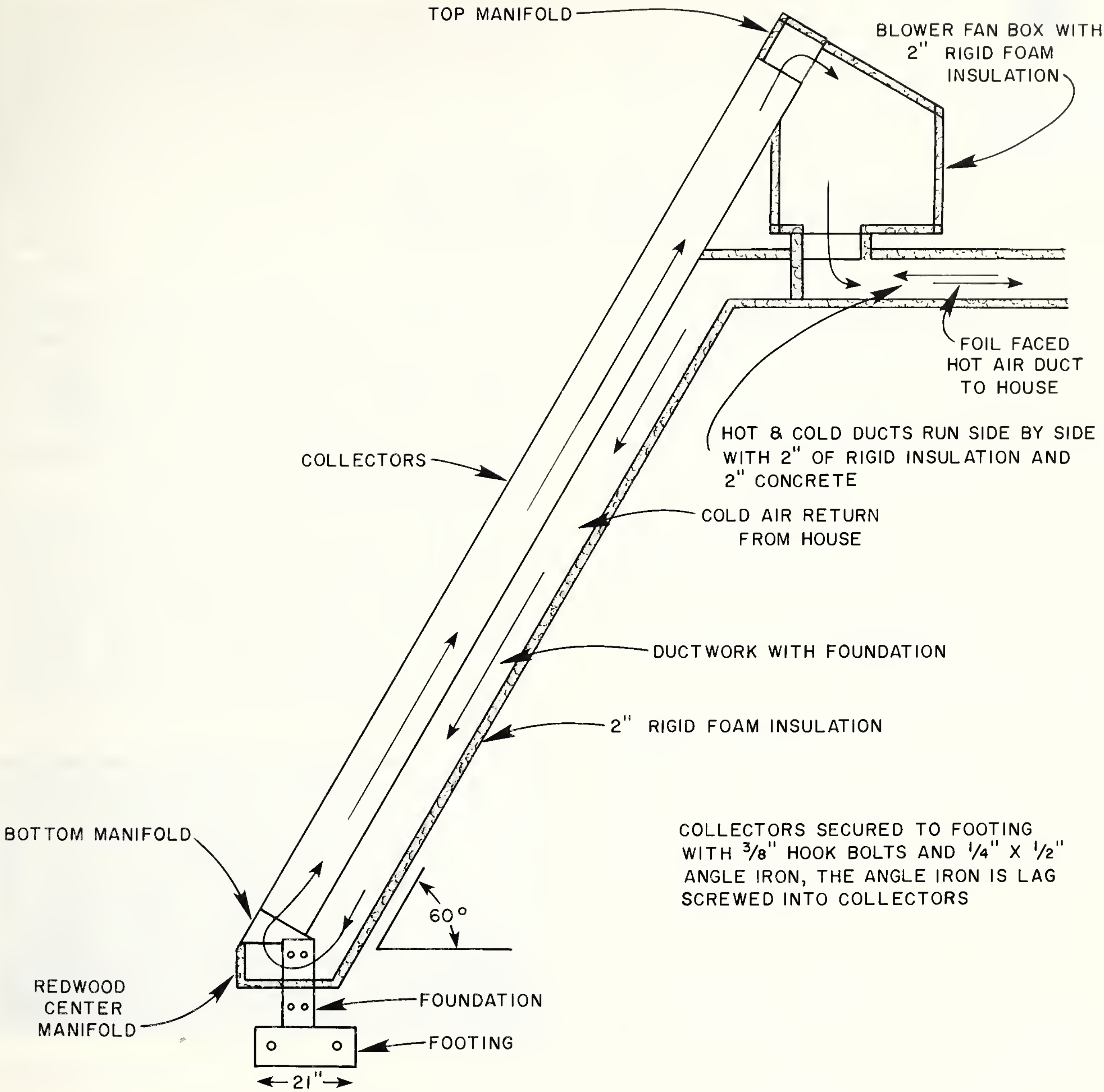
1) Building materials	$2,057
2) Equipment	345
3) Supplies	406
4) Communications, administration and planning	275
TOTAL	$3,083

SYSTEM PERFORMANCE AND ECONOMICS

In summer 1980, a mudslide damaged the collector, leaving the system inoperative. Renewable Energy Program engineers who visited the site theorized that the collector footings were not sturdy enough to resist the impact of the slide. Because the original owner has moved and the new owner has made no plans to rebuild the active system, all performance information presented here is based on only two years of informal monitoring.

The performance of this system generally met expectations, although the south-facing windows contribute considerably more passive heat than had been anticipated. Also, the performance of the collector indicates that the two home-built designs differ little in efficiency. Both designs are relatively inexpensive, and the simplicity of the roofing absorber makes it an attractive alternative for other do-it-yourself solar applications. The 576 square feet of collector surface delivered air at temperatures from 80° to 90 °F on a sunny winter day when the outside temperature was -10 °F. Although the system produced heat for an average of only four or five hours per day during the winter, Stoltz believes that with a storage component the fraction of the total heating load provided by active solar heating could have been increased.

A representative of the local utility company in Glendive estimated in 1979 that the annual home heating bill for the Stoltz residence was only one-half to two-thirds that of conventionally heated, comparably sized homes in the area. Savings such as these could amount to as much as $360 per year.


TOP MANIFOLD
BLOWER FAN BOX WITH
2" RIGID FOAM
INSULATION
FOIL FACED
HOT AIR DUCT
TO HOUSE
HOT & COLD DUCTS RUN SIDE BY SIDE
WITH 2" OF RIGID INSULATION AND
2" CONCRETE
COLLECTORS
COLD AIR RETURN
FROM HOUSE
DUCTWORK WITH FOUNDATION
2" RIGID FOAM INSULATION
BOTTOM MANIFOLD
COLLECTORS SECURED TO FOOTING
WITH 3/8" HOOK BOLTS AND 1/4" X 1/2"
ANGLE IRON, THE ANGLE IRON IS LAG
SCREWED INTO COLLECTORS
60°
REDWOOD
CENTER
MANIFOLD
FOUNDATION
FOOTING
21"

Glendive

Dennis Howard

Dennis Howard of Glendive was awarded a Renewable Energy Program grant of $6,000 in July 1977 to retrofit an active solar air system to his 928-square-foot, one-story home. Howard hoped to demonstrate that a homeowner in the Glendive area could save a substantial amount on fuel bills with a solar-heating system simple enough to be constructed by an energetic handyman.

Howard encourages the public to visit or contact him for information on his system. Correspondence should be addressed to Howard at River Road, Glendive, MT 59330; telephone 365-2261.

SYSTEM COMPONENTS AND OPERATION

The main component of this system is a Champion Model 160® solar furnace manufactured by International Solarthermics Corporation. The furnace consists of 160 square feet of collection surface in five 4-by-8-foot flatplate collector panels. The panels are mounted at a 60-degree angle on a well-insulated, wooden A-frame structure. Five compartments in the structure store collected solar heat. A door covering the collector serves as a reflector when open.

A solar system dealer calculated the necessary size of the unit from data supplied by Howard and delivered the unit complete with collectors, ducting, storage bin, properly sized blowers, and a controller. This kind of unit was chosen because the orientation and structural design of the home would not permit an attached or integrated design. Howard believes that the location of the solar furnace, which necessitated duct runs of 40 feet, is not ideal and that improved performance with less heat loss could be expected with shorter duct runs.

Washed rock, 1½ inches in diameter, was mixed with oversized rock to form the heat storage medium. Fifteen cubic yards of rock were used to create a ratio of 76 pounds of rock per square foot of collector area. Heated air is blown into the storage bin by an electric collector circulation fan. Heat is drawn from storage by a second fan, which moves the warmed air through 40 feet of insulated underground ducting to the cold air intake of the home's natural gas, forced-air furnace. The furnace, in the basement of the house, contains a blower to distribute the warm air to the living space. Cooled air is returned to the solar unit via another insulated duct running from the house to the collector.

A differential thermostat monitors the temperature of the collector, the rock storage bin, and the house to activate the controller for the two blowers in the solar unit. Whenever the temperature in the collector exceeds that of the storage bin, the collector fan circulates air through the collector into storage. When heat is needed in the living space, and if the storage bins are warm enough, another fan blows air through the rock bin and into the house.

The solar furnace controller has two settings. The first setting, a time delay, allows solar heat to be used for 25 minutes before the system switches to the original natural gas heating system. A second setting cuts off circulation of the solar heated air when the temperature in storage drops below 65 °F.

Although the manufacturer recommended continuous circulation of air through the home's heating system, Howard modified the design so that the furnace blower would operate only when heat was needed in the house. To accomplish this, he wired a relay into the furnace thermostat so that heat demand would activate the blower.

PROBLEMS AND MODIFICATIONS

Delivery of the solar furnace was prompt and construction of the entire system, undertaken by Howard without any contracted labor, was relatively trouble-free and fast. This is not to say that the task was simple or easy. Howard advises anyone seeking to duplicate this project that many hours of hard work were involved in digging the 40-foot trench for the ducting between the house and the solar furnace, and in sorting and washing multiple-sized rock for the storage bin. About 2½ truckloads of rock were washed by the shovelful in a tin sluice box. Although the rock had been washed by the supplier, Howard felt that it should be as clean as possible, since any dust or dirt would be blown into the heating system and, subsequently, the living space.

For the most part, this system was installed according to the manufacturer's suggestions and no major modifications were necessary, except for the change from continuous fan circulation mentioned previously. Howard considered changing the size of the storage rock from mixed small and oversized rock to all oversized rock to reduce airflow resistance in storage. However, a call to the manufacturer led to the conclusion that such a change was unwarranted. When problems developed with the controller to the solar furnace, the company replaced it with a model made by Honeywell.

Strong winds damaged the reflecting cover for the collectors on two occasions. A 2-by-4-inch frame built to hold and support the cover proved too weak for this purpose and the reflective material was torn and wrinkled. Wood and angle iron now are used with piano hinges to secure the cover, and dirt is placed under the cover to keep it from being lifted by the wind.

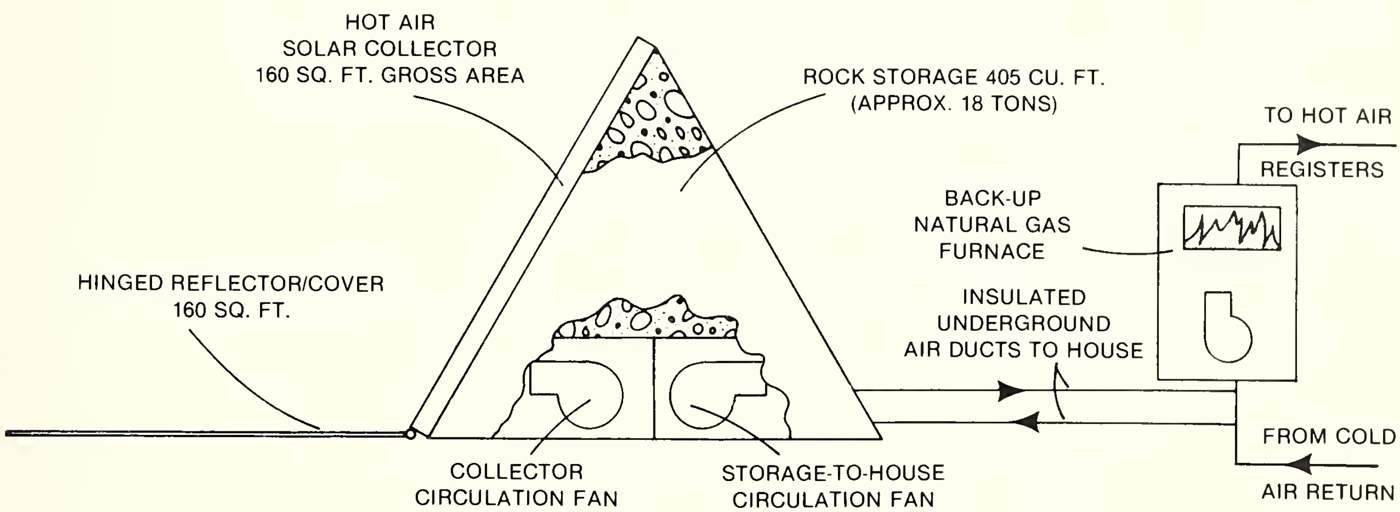
MATERIAL AND INSTALLATION COSTS

The total cost of the Howard system at 1977 prices was $5,931. Of this total, $5,378 was spent for the solar furnace, including all the necessary solar equipment. No attempt was made to calculate labor costs, since all the labor was supplied by the grantee over a period of about three months.

SYSTEM PERFORMANCE AND ECONOMICS

Data on the performance of this system have been compiled since 1977; the results have been mixed. Although the manufacturer suggested that the solar furnace would contribute as much as 55 percent of the annual heating load, in actual performance it has contributed only about 35 percent of the home's heating needs. Still, natural gas use in 1979 was less in any given month than during the previous three years. During the months of April, May, September, and October, nearly all of the space heat can be provided by the solar heating system.

Based strictly on economics, the system would seem to be a questionable investment. The annual savings that determine the length of the payback period will not be great. Because the cost of heating with natural gas is now relatively low, savings of about 35 percent may not provide a payback period shorter than the life of the project. Of course, this will depend on the future price of natural gas. The payback period also is uncertain because Howard's total utility bill has risen since the system began to operate. The solar circulation fans increased electrical use at a time when the costs of electricity and gas were rising.



Summary and

Conclusions

MONTANA SUNPOWER

MONTANA

DEPARTMENT OF NATURAL RESOURCES

& CONSERVATION

Energy Division ——— Helena, Mt. 59620

20,000 copies of this public document were published at an estimated cost of $1.2364 per copy, for a total cost of $24,728.00, which includes $19,728.00 for printing and $5,000.00 for distribution.